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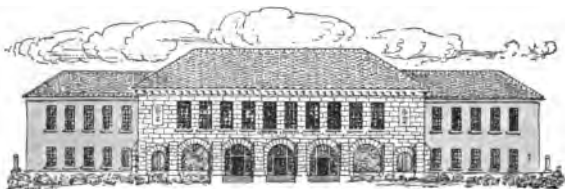
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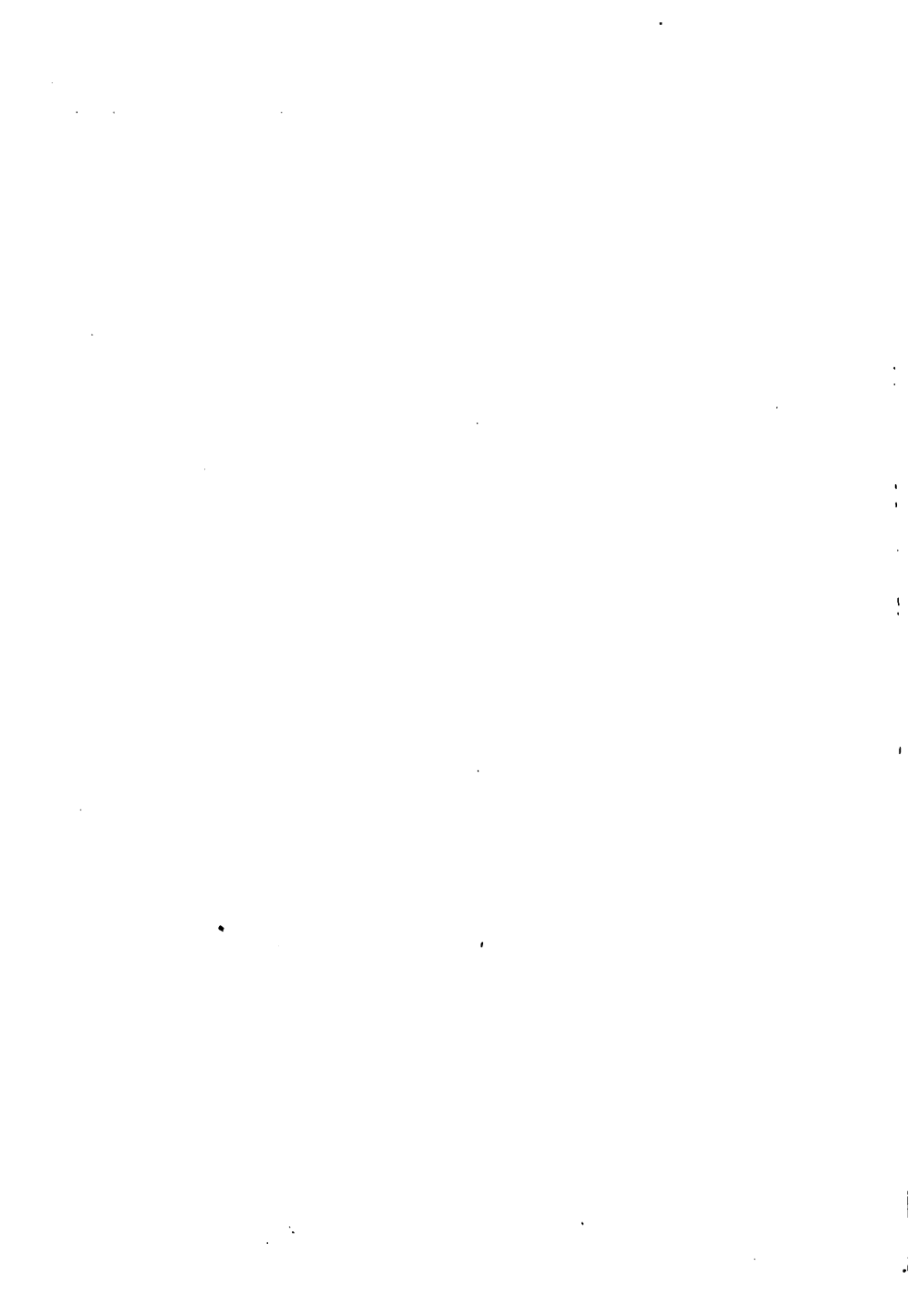
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PHYSICAL LABORATORY MANUAL

*FOR SECONDARY SCHOOLS
AND COLLEGES*

BY

CHARLES F. ADAMS, A.M.

TEACHER OF PHYSICS IN DETROIT CENTRAL HIGH SCHOOL



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PREFACE.

THIS manual is the outgrowth of several years of experience with pupils in the physical laboratory as well as of a study of the growth and development of laboratory work in secondary schools. The development of the work in my own hands has been attended with an elimination of qualitative exercises, or illustrative experiments, and a reduction of the number of exercises at first attempted. My experience and study lead me to believe that the best results are attained by comparatively few exercises, the greater part of them being quantitative in character. Quality of work, rather than quantity, should receive the most consideration. The tendency in my own work has been to strive after greater accuracy from year to year. To allow pupils to do quantitative exercises in a careless manner, with small regard for accuracy, is to do them an injury. Under these circumstances a quantitative exercise ceases to be such and becomes qualitative; and, moreover, it is a pretense and a sham. The position here taken as to number and kind of exercises is, I believe, in accord with the best thought and practice of the time. In support of this it is necessary only to mention the report of the Physical Conference to "The Committee of Ten."

In the selection of experiments and methods of procedure great care has been taken to adopt only those that are capable of giving results of a considerable degree of accuracy in the hands of pupils. Regard has also been paid to those demanding inexpensive and

durable apparatus. Perhaps to some a few of the exercises may appear to be too difficult, but it is believed that they should be such as to demand the very best thought and endeavor the pupils are capable of giving, while at the same time not being beyond their capacity.

In the presentation of the subject matter, it has been my aim to make the instructions so clear and explicit that the pupil need not go wrong, and to select that order of procedure that will give the best results. Here again accuracy has been one of the chief considerations. It has also been my endeavor to develop in the pupils the power of independent thinking, and to that end to withhold from them that which they ought to be able to think out for themselves. Very often too much help is given to the pupil in the laboratory rather than too little.

It is with pleasure that I acknowledge my indebtedness to the excellent manuals and text-books in common use, and to the many teachers and instructors in physical science from whom I have received valuable suggestions while preparing this work. I wish also to acknowledge my obligation to Prof. John O. Reed, of the University of Michigan, for valuable hints.

C. F. ADAMS.

DETROIT, MICH., October, 1896.

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BOOKS OF REFERENCE

	Indicated by
Avery's School Physics	Av.
Carhart & Chute's Elements of Physics	C. & C.
Carhart's Primary Batteries	C.
Deschanel's Natural Philosophy	D.
Everett's C.G.S. System of Units	E.*
Fleming's Short Lectures to Electrical Artisans	F.*
Gage's Principles of Physics	G.
Ganot's Physics, 14th Edition	Gt.*
Glazebrook & Shaw's Practical Physics	G. & S.*
Hall & Bergen's Physics	H. & B.
Hopkins's Experimental Science	H.*
Kohlrausch's Physical Measurements	K.*
Lodge's Mechanics	L.*
Niandet's Electric Batteries	Nt.
Nichol's Laboratory Manual, Vol. I.	N.
Sabine's Laboratory Course in Physics	S.
Stewart & Gee's Elementary Practical Physics	S. & G.*
Thompson's (S. P.) Elementary Lessons in Elec. and Mag.	T.*
U. S. Pamphlet for Voluntary Observers	U. S.*
Worthington's Physical Laboratory Practice	W.*

* Especially useful.

INTRODUCTION

THE student should not enter the laboratory with the expectation that it is to be a play-room, and that he is to amuse himself with ingenious toys; if he does, he is likely to be disappointed. He will find it a place for the exercise of his keenest thought and plainest common sense, a place for painstaking patience and perseverance.

The time allowed for laboratory work in most schools is necessarily short,—two to three hours per week at most. To make the best use of this time the pupil should come to the laboratory well prepared for the work to be done, having previously studied the exercise thoroughly and having the tabular form ready for the recording of the data. No work should be done in the laboratory that can just as well be done at home.

The Note-book.—The note-book is one of the essential features of laboratory work; it is hardly secondary to the experimentation itself. The pupil should understand that ability to make a neat, clear, legible, and accurate record of anything is an acquisition to be desired; and that to give a simple straightforward description of an object, or an occurrence, is an art worth cultivating. Simplicity and clearness of expression are necessary to clear thinking. The aim of the pupil should be to make the notes so

clear and plain that one unfamiliar with the work can readily understand them.

Precision of statement is also worthy of the pupil's attention, and should receive special consideration in the note-book. Great care should be taken that the language means exactly what it is intended to mean; and also that the notes truthfully conform to the results found in the laboratory, without pretense that they wholly accord with the demands of theory, if in fact they do not.

The laboratory note-book gives unusually good opportunities for the cultivation of all these things,—clearness, simplicity, precision, scientific accuracy, and scientific truthfulness of expression.

The habit of making the first record neat and accurate should also be cultivated, and the labor of copying and the mistakes incident thereto avoided. This requires foresight and method. The constant use of the eraser and the recording of data on loose sheets of paper should by all means be avoided. A result should be recorded in *its proper place* in the note-book the *moment it is obtained*, unless the work is merely preliminary for the sake of practice, or for testing the apparatus. The book should be of good material and used exclusively for this work. To afford room for the tabular forms and for cross-section paper, one $7\frac{1}{2}$ or 8 in. wide is to be preferred.

All pieces of apparatus should be numbered or have distinguishing marks, of which a record should always be made by the pupil. If this is done, labor will often be saved, when it is found necessary to verify any results by repeating an experiment. It often happens that it is impossible for a pupil to rectify a mistake because of neglect of this precaution.

The following order and headings are suggested for the note-book, four pages at least being necessary for most ex-

periments: Use as headings or topics, (1) Purpose, (2) Apparatus, (3) Operations, (4) Discussion, (5) Conclusion, and (6) References. Place these headings in the margin. Beginning on the left-hand page, write at the top the serial number of the exercise, the manual number, and the date. Place at the top of the right-hand page the tabular form. This can be done before coming to the laboratory. The tabular form being at the top of the page, the columns can be extended downward as the work proceeds in the laboratory. The entire right-hand page should be reserved for numerical data, mathematical calculations, and the like.

The first, or left-hand page, will usually afford sufficient space for the treatment of the topics, "Purpose," "Apparatus," and "Operations," the remaining topics being placed on the third and fourth pages.

Under "Purpose," state the object of the exercise, or the problem to be solved. Very often the purpose will be to show the relation between dependent phenomena,—to verify a physical law.

Under the heading "Apparatus," give a list of the pieces used, and generally a brief description of the more important parts and conditions. Very often drawings or diagrams are desirable and should be placed under this head. Shaded drawings, however, are not to be encouraged.

Under "Operations," give a simple narrative of the method of procedure. No numbers from the tabular form should be introduced into this narrative, but the statements should be general so as to be applicable to all of the numerical data.

Under the heading "Discussion," give a simple mathematical analysis, showing how the data of the tabular form are used to verify the truth taught by the exercise. This topic should include some account of the theory of the exercise and also a statement of the sources of errors that occur.

The "Conclusion" should contain a statement of the infer-

ences to be drawn from the exercise or the results of the mathematical calculations.

Under "References" give references to text-book, manual, and other books consulted on the experiment.

The following quotation from an address by President Eliot of Harvard sets forth very clearly the value of laboratory work in science and indicates the important share that the note-book should have in it:—

"These, then, are the four things in which the individual youth should be thoroughly trained, if his judgment and reasoning power are to be systematically developed: Observing accurately; recording correctly; comparing grouping and inferring justly; and expressing cogently the results of these operations."

The following are some of the most common faults in note-book work:—

(1) Frequent erasures. If a mistake is made, the book should not be disfigured by erasures, by drawing lines through the work, or by cutting out the leaves. It is much better to make a note in the margin explaining the mistake. Corrections made in this way are evidence of the honesty of the work.

(2) Crowding the notes. This fault is very common. Generous spaces should be left between the different parts of the notes for additions and corrections after discussion with the teacher.

(3) Disregard in drawing conclusions of the data obtained in the laboratory. Pupils often state conclusions drawn from their knowledge of the subject obtained from the text-book, not from their own work.

(4) Use of common fractions instead of decimals.

(5) Use of the imperative mood in descriptive notes. The pupil is not instructing another how to perform the experiment.

(6) A disinclination to record the result of an observation, if it happens to accord exactly with a previous

observation. To obtain the same result several times in succession, is not necessarily evidence of especially accurate work.

After the notes are completed, they should be discussed with the teacher; and after the discussion, they should be revised and corrected. This discussion should, if possible, be a personal one. With large classes, however, this is often impossible. In that case some part of the recitation time should be devoted to the discussion of laboratory exercises.

For the purpose of criticising notes, some system like the following is convenient:—

1 to indicate bad English, wrong spelling, capitals, or punctuation;

2, lack of neatness, bad form, or crowded notes;

3, incompleteness, or meagerness;

4, incorrect data, or calculations;

5, false reasoning, absurd or false statements;

6, notes in general bad;

7, weak or unsatisfactory in parts;

8, consult the teacher at once;

9, commendation;

X, unnecessary statements.

Calculation of Results. — The study of physics has become very largely a science of measurement. The student should bear in mind, however, that perfect accuracy of measurement is unknown and impossible. For example, if a certain length is said to be 1.26 cm., it is not to be understood that the following places, if filled out, are ciphers, but that they are unknown.

The differences between observed values and true values are called **errors**. Errors are to be distinguished from *mis-*

takes, which are the result of carelessness and inexperience. Errors must always exist; mistakes ought never to occur. But because mistakes are likely to happen, especially with beginners, a single determination of any quantity is of little value, and several determinations should always be made. If there is good reason for believing that an observation is affected by a mistake, it should be rejected; but the pupil should not therefore reject an observation simply because it differs from other observations of the same quantity.

Some errors are **constant**. They are those that are due to known causes, and always affect the result in the same direction; that is, making it always too large or always too small. Such errors, when due to the apparatus, are called **instrumental** errors. Constant errors are allowed for by corrections and by changing the conditions of the experiment. No general rules can be given for their elimination; each one is a subject for special consideration.

Errors due to unknown causes and to uncertainty of observation are termed **accidental**. Such errors give results that are as likely to be above as below the true value. They are eliminated, in part at least, by the method of *averaging*,—a method that does not apply to constant errors.

A consideration of the errors of an experiment is valuable, because it enables one: (1) To judge of the accuracy of the results, (2) To see what abbreviations of the calculations are allowable, (3) To see what part of an experiment needs most care, and (4) To see how the error may in part be eliminated.

The degree of accuracy attainable differs very much in different experiments. Generally an accuracy of one part in a hundred, or an error of not more than one per cent, will certainly be all that can be expected from beginners in this work.

If an accuracy of 1 part in 100 only is to be obtained, then *only three* digits are necessary to express the result; if 1 part in 1000, then four digits *only* should be used. For example, suppose 243.7868 c.c. be obtained as the result of an experiment, but that it is known to be accurate only to 1 part in 100; then only three figures of the result should be kept, 244. One is added to the last figure, because the following one is greater than 5. To keep more of the figures is worse than useless. In the first place, it is misleading and untruthful, for it implies that the accuracy is greater than it really is. *Precision* of statement is as important as accuracy of the result. In the second place, unnecessary labor was probably used in calculating it, and if it were used in further calculations, more unnecessary work would be done. It is customary to keep one uncertain figure in all results.

When several determinations enter into a result as *factors*, the final result *can never be more accurate than the least accurate factor*. For example, suppose that one factor is known to be accurate to 1 part in 1000, one to 1 part in 100, and one to 1 in 10000; the result can only be accurate to 1 part in 100, and if the result be 3245.4798, or 32.454798, or 0.00032454798, only three of the digits at most should be retained. The answer would be 3250, or 32.5, or 0.000325.

To illustrate these principles further, the following data are taken from a student's note-book:—

Rise in temperature	3.1°.
Water taken	378.2 g.
Mass of copper	153.5 g.
Change of temperature . . .	80.6°.

To obtain the desired result the data were used as follows:—

$$\frac{3.1 \times 378.2}{153.5 \times 80.6} = \frac{1172.42}{12372.10} = 0.09476.$$

The least accurate factor in the data is the 3.1° . The tenths of a degree were estimated, and hence there is an element of uncertainty about the 0.1 in that number.

We can judge first of the accuracy of the result. There will be the same order of uncertainty in the result as in the 3.1; that is, only the first significant figure is certain, and the next is uncertain, and those that follow are wholly unknown. All after the 4 should be dropped.

In the second place, we can see what factor needs most care in its determination. As far as the accuracy of the result is concerned, it is wholly useless to determine the weights to tenths of grams. In fact, an error of 10 g. in the determination of the weights would not have affected the accuracy of the result any more than an error of 0.1 of a degree in the rise of temperature.

In the third place, we can see what abbreviations of the calculations are allowable. Dividing 1170 by 12400 will give 0.094, a result as accurate as the one given above, where all the figures were used. This shows that both the multiplications and the division could have been shortened.

In the fourth place, the error in the 3.1° is an accidental one, and hence the average of several determinations would tend to make the result accurate to one more place.

The following example will illustrate one method of abbreviating multiplication: What is the product of 87.64 by 23.59, the last figure of each being uncertain?

$$\begin{array}{r}
 87.64 \\
 \times 23.59 \\
 \hline
 \text{Reversing the usual order of multiplying, } (2 \times 87.64) = 1752.8 \\
 \text{Dropping last figure of multiplicand, } (3 \times 87.6) = 262.9 \\
 \text{Dropping one more figure of multiplicand, } (5 \times 87) = 43.8 \\
 \text{Dropping another figure of multiplicand, } (9 \times 8) = 7.8 \\
 \hline
 2067.3
 \end{array}$$

The same number is carried each time as would have been carried had all of the figures of the multiplicand been used. The 7 in the result is uncertain, and the next figure consequently is unknown and should be dropped. The result is therefore 2067. The labor saved will be appreciated by multiplying the two numbers in the usual way, and comparing the work with this.

In recording measurements, all the decimal places should be kept which the accuracy of the method used permits. For example, if the instrument measures to hundredths of a centimeter, and a measurement of exactly 2.8 cm. is obtained, it should be recorded as 2.80 cm., not 2.8 cm. The first signifies that hundredths of centimeters were measured, the last that no attempt was made to measure beyond tenths.

Interpretation of Results.— It is quite as important for the pupil to appreciate the meaning of his data as it is for him to obtain them. Two rules will assist him in this respect: When the *quotient* of two variables is *constant*, the two quantities are *directly* proportional. When the *product* of two variables is *constant*, the two quantities are *inversely* proportional.

Graphic Representation of Results.— When two quantities are so related that any change in the value of one causes a change in the value of the other, it is often very advantageous to represent the relation between them graphically.

Paper ruled in small squares is used for the purpose, called cross-section paper (see Fig. 1). The most useful kind is that ruled in centimeters and millimeters, or in inches and twentieths of an inch, each tenth line being heavier than the rest.

A corner, *O*, of one of the squares, usually in the lower

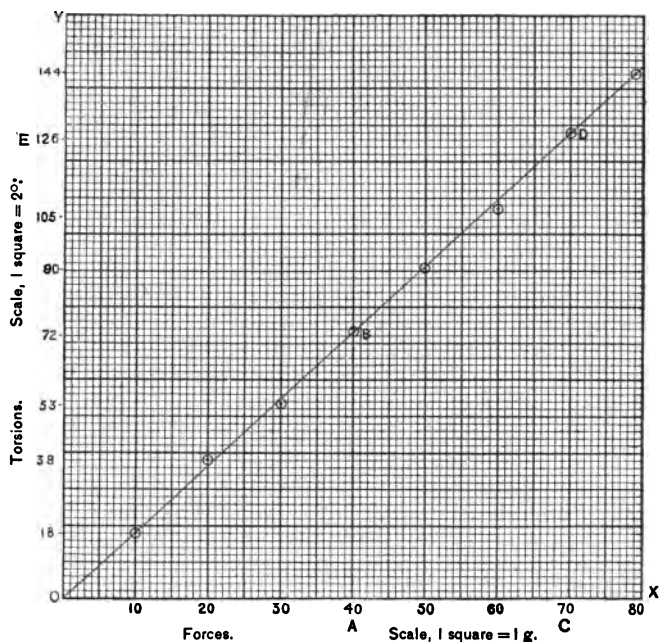


Fig. 1.

left-hand corner, is selected for the **origin**, and the lines OX and OY are drawn through this point. These are called the **axes**, OX being the axis of **abscissas** and OY the axis of **ordinates**.

Suppose it is desired to represent the relation between the twist, or *torsion*, of a wire and the *force* producing the torsion, an experiment having given the following data: —

A force of 10 g.	produced a torsion of 18°.
" " 20 g.	" " " 38°.
" " 30 g.	" " " 53°.
" " 40 g.	" " " 72°.

A force of	50 g.	produced a torsion of	90°.
" "	60 g.	" "	105°.
" "	70 g.	" "	126°.
" "	80 g.	" "	144°.

On OX distances are laid off to represent the several *forces*, and on OY distances to represent the several *torsions*. In laying off these distances some scale must be selected to represent a unit of force, and one also to represent a unit of torsion, not necessarily the same scale for each. Convenience and the size of the paper are the chief considerations in selecting the scale, which should be as large as the size of the paper permits considering the *largest* value to be represented.

At the intersections of the horizontal lines extending from the places marked on the axis of ordinates and the verticals from the places marked on the axis of abscissas place small dots, or crosses. Each of these dots represents both a *force* and a *torsion*. The quantities represented on OX and OY are together called the *co-ordinates* of these points. Thus, OC and OE are the co-ordinates of the point D .

The line joining these dots represents the relation existing between these quantities. It may be a straight line, quite as often it is a curved line. The simpler the curve, the more simple the law expressing the relation between the quantities.

In connecting the dots by a line draw a smooth regular line, or curve, that will hit most of the points, not a broken one that will touch all of the points. If some of the dots fall out of such a line, either there was an error in the data or the relation between the quantities is not a simple and a constant one.

If the line is a straight one, it can be shown by geometry that they are directly proportional to each other. Thus,

OAB and OCD are similar triangles and $OA : OC :: AB : CD$, but OA and OC represent *forces* and AB and CD *torsions*.

The scale on which the curve is drawn should always be indicated along the two axes. Negative quantities are plotted to the left and below the origin.

Method of Using a Scale. — In using a scale, its marked edge should be placed as near as possible to the object being measured. If the thickness of the rule, as in Fig. 2, inter-

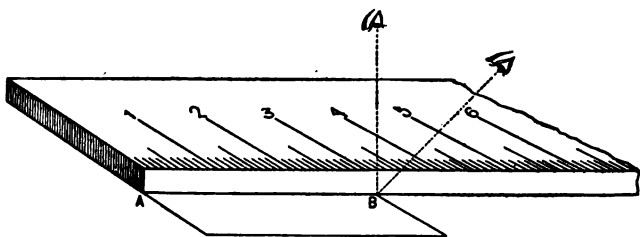


Fig. 2.

venes, an error is likely to arise due to parallax, or a wrong position of the eye. This will be avoided by placing the rule as shown in Fig. 3.

The first method is bad also because the measurement begins at the end of the rule. This may cause an error;

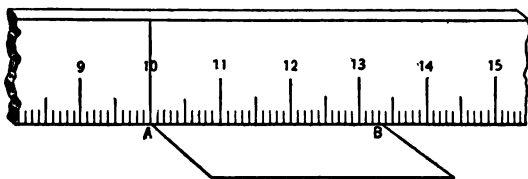


Fig. 3.

because the end of the rule, or scale, may be imperfect, and also because it is often difficult to adjust the thing measured so that it is exactly even with the end.

In general, it is better not to start at the zero of any scale to measure, but to take the difference between two points on the scale, as shown in Fig. 3. The pupil should learn to estimate tenths of the small divisions of a scale.

The Beam Balance. — Fine chemical balances are inclosed in glass cases to exclude the dust and to protect the balance from currents of air. When not in use, the beam is raised from the knife-edges; and there are rests under the pans to steady them. The beam is lowered for use by turning a milled head in front of the instrument, and the rests underneath the pans are lowered by pushing in a small stop or pin.

Before the balance is used each day, it must be leveled; this is done by a spirit-level usually attached to the instrument. The position also of the pointer on the scale, when the beam is at rest, must be determined. Generally the pointer, when the beam comes to rest, will be found *not* to coincide with the middle point of the scale, and it is not well to attempt to adjust it to that point. It requires too much time to wait for the beam to cease swinging in order to determine the position at which the pointer would come to rest; and hence the position of rest is found by observing the turning-points of the index, while it is vibrating, and taking the mean of these points. The position of rest, however, is not midway between any two consecutive turning-points, since friction and the resistance of the air reduce the amplitude of vibration at each swing; but it is found by taking an odd number of turning-points, say 3 to the left and 2 to the right. This will throw the greatest and the least on the same side. For example, suppose the pointer to move over a scale having twenty divisions, and imagine these divisions to be numbered from 0 on the right to 20 on the left (not from the center in both directions). (See Fig. 4.) Suppose the following observations are taken: —

TURNING-POINTS.

Right.	Left.
6.4	14.6
6.8	14.0
7.4	

$$3 \overline{)20.6} \qquad 2 \overline{)28.6}$$

Mean to the right = 6.9

14.3 = mean to the left.

6.9 = mean to the right.

$$2 \overline{)21.2}$$

10.6 = position of rest.

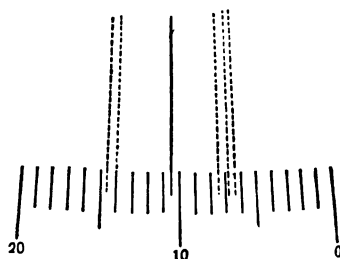


Fig. 4.

In weighing a body, weights are placed on the pan until a nearly perfect balance is obtained, and then the position of rest is again obtained as above. Suppose it to be 8.8; then, if the weights are in the right-hand pan, there are too few of them, and the pointer lacks $(10.6 - 8.8)$ 1.8 divisions of being in the right place. Add 1 mg. to the pan, and again find the position of rest. Suppose it to be 9.6. Then 1 mg. causes a change in its position from 8.8 to 9.6, or $(9.6 - 8.8)$ 0.8 of a division. It will take as many milligrams to change it 1.8 divisions as $1.8 \div 0.8 = 2.25$ mg. Hence the true weight will be 2.25 mg. more than the weight first found. If the position of rest had been 1.8 to the left of the zero position, then the 2.25 would have been subtracted.

The number of scale divisions the position of rest is changed by 1 mg. is termed the **sensitiveness** of the balance. This changes with the load, and should be determined for every 10 g. up to the full load allowed for the balance. Thus, to determine the sensitiveness for a load of 40 g., place 40 g. in each pan and then determine the position of rest; then add 1 mg. to one pan and again determine the position of rest. The change in the position will be the sensitiveness for that load.

Using the loads and the sensitiveness for each load as co-ordinates, plot a curve showing the relation of each to the other. If this curve is preserved, it will save the trouble of finding the sensitiveness of the balance for every weighing that is made.

Rules for Weighing.—(1) See that the balance is level and that the pans are free from dust. Use a camel's-hair brush for removing the dust.

(2) Place the object to be weighed in the left-hand pan and the weights in the right-hand pan of the balance.

(3) See that all of the weights are present in the box before beginning to weigh, and place the box conveniently near the right-hand pan.

(4) Never place objects or weights on the pans, nor remove them from the pans except when the beam is raised from the knife-edges and the balance is at rest.

(5) In arresting the beam, always wait until the pointer is over the center of the scale. The beam should always be raised slowly and carefully to avoid injuring the knife-edges.

(6) Never touch the weights with the fingers, but lift them with forceps provided for the purpose.

(7) The weights should never be anywhere but on the pan or in their places in the box.

(8) Use the weights in the order in which they are placed in the box from the largest to the smallest, *omitting none*.

(9) Check the final result that has been found by adding the weights on the pan, by noting the vacant places in the box and adding the weights belonging therein.

(10) The object to be weighed should be cool, and nothing that is wet or that would injure the pan must be placed directly upon it.

(11) Final observations must be taken with the balance case closed to avoid currents of air; and the position of the observer should be central, so that the line of sight shall be normal to the scale.

Rules (2), (3), (7), (8), (9), and (10), apply as well to larger and coarser balances and weights, and should *always* be observed.

PHYSICAL LABORATORY MANUAL



CHAPTER I

SIMPLE MEASUREMENTS

[The following exercises should be preceded by a few exercises in simple measurement, such as measuring the length and width of the laboratory table, or the dimensions of the room. The average of several measurements of the same thing should always be taken. Such exercises can readily be devised and multiplied by the teacher according to the time at his disposal.]

EXERCISE I

THE DIAGONAL SCALE

References. — S. & G., Vol. I., pp. 4–6.

Apparatus. — A pair of dividers with sharp points. A diagonal scale (Fig. 5). A strip of brass with two small crosses ruled upon it.

Operations. — (1) Determine the unit of the scale.

(2) Count the number of spaces into which the unit of the scale is divided by the diagonal lines at one end of the scale. Also count the number of spaces formed by the lines running lengthwise on the scale.

(3) Note that the diagonal lines and the horizontal lines form a large number of small parallelograms.

What is the length of the top and bottom of each of these parallelograms?

(4) Note that the first diagonal line, the one starting at the zero of the scale, forms with the vertical from the same point a triangle.

How long is the base of this triangle?

(5) By geometry determine the length of all the lines in that triangle parallel to its base.

(6) How far is it, for example, on the fifth horizontal line from its intersection with the vertical from zero to its intersection with the second diagonal? On the third horizontal line? fourth? fifth? etc.?

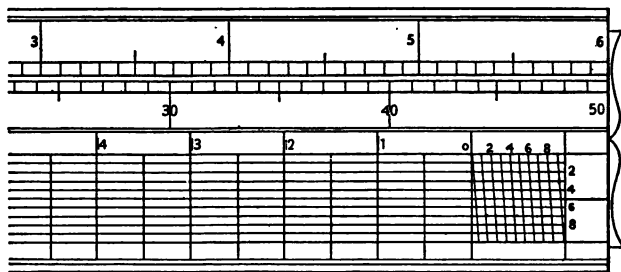


Fig. 5.

How far is it from the vertical on the fifth horizontal to the fourth diagonal? to the sixth diagonal? eighth? ninth?

(7) What do the diagonal lines represent or express? What the horizontal lines?

(8) By the aid of the scale, spread the points of the dividers so that they shall be 2.67 units apart; 3.08 units apart; 1.45; 2.11. Let the instructor verify in each case.

(9) By the dividers and the diagonal scale measure the distance between the points of intersection of the two crosses on the strip of brass. Let the instructor verify the measurement.

N.B.—Both points of the dividers must always be on the same horizontal line.

It will be found convenient for the instructor to keep a record of the distances between the crosses on the strips of brass, the strips being stamped with a number and passed around the class. Each pupil can thus report his measurement, and the instructor can easily verify.

EXERCISE II

THE VERNIER

References. — American Cyclopaedia, art. Vernier; D., p. 145; Gt., art. 10; S. & G., p. 7.

Apparatus. — A model vernier (Fig. 6), consisting of a board about $5 \times 16 \times 1$ cm., on which a scale is marked

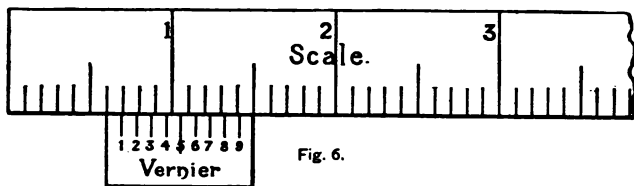


Fig. 6.

having a unit about a decimeter long, each unit being divided into ten equal parts; another piece of wood about $12 \times 3 \times 1$ cm., on which are marked off ten divisions equal to nine divisions on the larger scale. The larger one constitutes the scale, and the smaller, the vernier. Instead of the model vernier, any instrument having a scale and vernier, such as a verniered caliper, may be used.

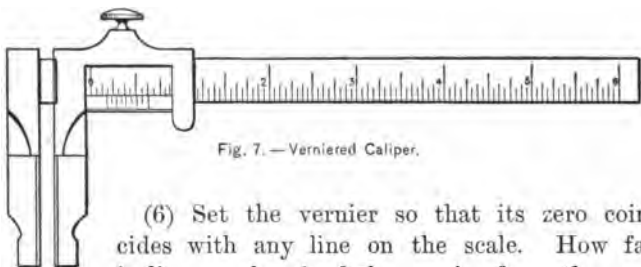
Operations. — (1) Determine what constitutes the unit of the scale.

- (2) How long is each division of the unit?
- (3) How long is the vernier?
- (4) How long is each division of the vernier?

(5) What is the difference in length between one division of the scale and one of the vernier?

Answer the above questions in terms of the unit of the scale, and in decimal, not common fractions. Write the questions and their answers in your note-book.

The answer to the last question constitutes the **least count** of the vernier, and it determines to what part or fraction of the unit the measurement can be taken.



(6) Set the vernier so that its zero coincides with any line on the scale. How far is line number 1 of the vernier from the zero of the scale? How far is the zero of the vernier from the zero of the scale? If the vernier is moved along until its line 1 coincides with the next line of the scale, how far has it been moved? How far is the zero of the vernier from the zero of the scale? If moved so that its line 2 coincides, how far has it been moved, and how far is the zero of the vernier from the zero of the scale? line 3? line 4? line 5? etc.? When the sixth line of the vernier coincides with a line on the scale, into what parts does the zero of the vernier divide a division of the scale? When the seventh line coincides? eighth line? third line? etc.?

EXERCISE III

THE MICROMETER SCREW

Apparatus.—The micrometer screw is an instrument for measuring small dimensions with great accuracy. The screw *C* (Fig. 8) is turned by the head *D*, which is a hollow cylinder surrounding the shaft *a*. On the shaft *a* is a linear scale corresponding to the pitch of the screw. Suppose the pitch to be $\frac{1}{40}$ (0.025) of an inch. In that case, the linear scale would be divided into tenths of an inch, and each

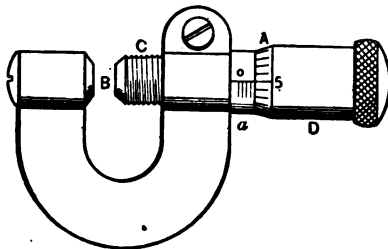


Fig. 8.

tenth into four equal parts, or fortieths (0.025) of an inch. When the screw is turned one whole revolution, it will move lengthwise $\frac{1}{40}$ (0.025) of an inch, and the beveled edge *A* of the cap will pass over one division of the linear scale. This beveled edge is also graduated, its circumference being divided into twenty-five equal parts. When the screw *C* is in contact with *B*, the beveled edge *A* should coincide with the zero of the linear scale, and the zero of the circular scale on *A* should coincide with a line running lengthwise of the linear scale.

When the screw is turned through one of the divisions of the circular scale, it of course makes $\frac{1}{25}$ of a revolution

and moves lengthwise $\frac{1}{25}$ as far as it does when turned once around; that is, $\frac{1}{25} \times \frac{1}{40}$, or in the decimal form $\frac{1}{25}$ of 0.025, which is 0.001 of an inch. Each division of the circular scale, therefore, measures 0.001 of an inch. It is easy, however, to estimate tenths of these circular divisions, and thus to read by this instrument to 0.0001 of an inch.

Not all instruments of this kind have exactly the same graduations as those described above. The pitch of the screw and the number of divisions on the circular scale may be different, but the principle of all is the same.

Operations. — (1) Determine the pitch of the screw; that is, the value of one of the divisions of the linear scale. If this cannot be done by inspection, turn the screw back until a considerable portion of the scale is visible, and then by a pair of dividers compare twenty, or more, divisions of it with both English and metric standard rules.

(2) Ascertain the number of divisions in the circular scale and calculate their value, as described above.

(3) Place a wire, or some object to be measured, between *B* and *C*, and turn the screw until it is just tight enough to hold it there. In doing this, *hold the head D lightly, so that as soon as contact occurs the fingers will slip, otherwise there is danger of straining the screw and flattening the wire. Never turn the screw up hard.*

(4) To obtain the result, count the number of whole divisions of the linear scale exposed to view and add to their value the fraction of the last division obtained by reading the circular scale.

Support the screw in the left hand by taking hold at the bend of the frame. Before the screw is turned, let the instructor verify your reading.

Practice in the use of the instrument should be continued until it can be read with ease and accuracy.

EXERCISE IV

THE JOLLY BALANCE

References. — S. & G., Vol. I., pp. 163, 186.

Apparatus. — A Jolly balance (Fig. 9). A set of metric weights.

Operations. — (1) Read and record the position of the index of the spring with no load in the pan, avoiding **parallax**, or the apparent displacement of the index due to the different positions of the eye, by placing the eye so that the index exactly covers its own image in the mirror.

(2) Place 5 g. in the pan, and take the position of the index again.

(3) Repeat with 10, 15, 20, 25 g., etc., always reading and recording the position of the index both before and after using each weight.

(4) Repeat the above with the same weights after having moved the spring a short distance up or down to change its zero position.

Record the data as fast as obtained in a table like the following: —

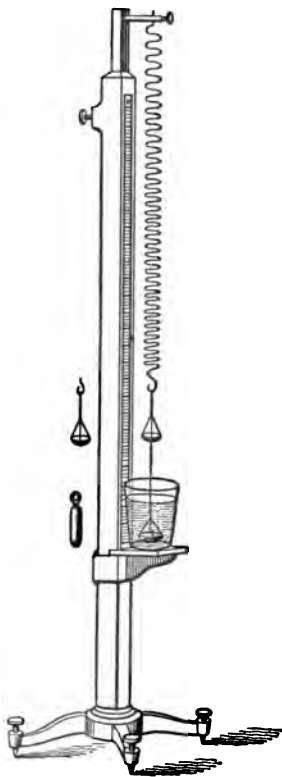


Fig. 9.

BALANCE NO.		SPRING		MODULUS	
Reading without Load.	Average without Load.	Reading with Load.	Load.	Elongation.	Elongation per Gram.
$\frac{1}{2}$ *	1	1	1	1	1

(5) From the above table find the relation between the load and the elongation. (An illustration of Hooke's law.)

(6) Calculate how many grams are necessary to elongate the spring one centimeter. This will be the **modulus** of the spring. (See H. & B., p. 14, note.)

(7) Knowing Hooke's law, what use can be made of the modulus?

(8) What relation exists between the load and the elasticity (power of recovery) of the spring? and hence between the elasticity and the elongation?

(9) Is the elasticity of the spring perfect? (See H. & B., p. 13).

The conclusions to be derived from this exercise are indicated by paragraphs (5), (6), (7), (8), and (9).

(10) Using the elongation and the load as co-ordinates, plot a curve showing the relation between them, and fasten the paper upon which it is done in your note-book.

NOTE.—Hooke's law states that when a body is distorted within the limits of elasticity, the force with which it reacts is proportional to the amount of the distortion.

The force applied and the reaction (elasticity) together constitute a **stress**, and the distortion is termed a **strain**.

* The numbers in the columns of the tabular forms indicate inches, and are intended to suggest roughly to the pupil a suitable width for the columns when the tabular form is placed in the note-book.

EXERCISE V

DENSITY OF A RECTANGULAR PRISM

References. — For equivalents for reducing metric units to English units, see appendix, p. 169, and Everett's C.G.S. Units, introductory pages.

Apparatus. — A Jolly balance. Steel rules, verniered calipers, or dividers and diagonal scale. A small rectangular prism of wood.

Operations. — (1) Measure the length, breadth, and thickness of the block several times, each time in a different place.

(2) Weigh the block by the Jolly balance.

(3) From the average of the measurements taken, find the volume of the block, and calculate the mass of 1 c.c. (cubic centimeters) of the substance composing the block. This will be the **density** of that substance. What is density?

(4) Repeat the above, using English instead of metric units, and finding the mass (expressed in ounces) of 1 cu. in.

If means are not at hand for finding the weight in ounces, reduce the weight in grams to ounces.

As a test of the accuracy of your work, reduce the volume in cubic centimeters obtained by measurement to cubic inches, and the volume in cubic inches to cubic centimeters. In making the calculations for this exercise, observe carefully the instructions given on pp. 15, 16, and 17. Do not retain more figures in your results than the accuracy of the methods used justifies. How many figures in each measurement are certain? In the average dimensions obtained, how many of the figures are certain? which ones are uncertain? which are unknown? Use the method of multiplication given on p. 16.

Tabulate the data as follows:—

OBJECT.....*						
Metric Units.				English Units.		
	Length.	Breadth.	Thickness.	Length.	Breadth.	Thickness.
$\frac{3}{4}$ 1	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$
2						
3						
4						
etc.						
Average						
Volume						
Reduced volume						
Weight						
Density of						

EXERCISE VI

DENSITY OF A CYLINDER

Apparatus.—A small cylinder of brass or other metal. Calipers, steel rules, or dividers and diagonal scale. Two square-cut blocks (Figs. 10 and 11) and a meter-stick.

Operations.—(1) Find the average dimensions of the cylinder, being careful to measure its diameter at several different places and in different directions.

The diameter may be measured either by calipers or by placing the cylinder between two square-cut blocks whose sides are placed against a ruler and then measuring the distance between the blocks. Do not begin at the end of

* State the kind of wood or the name of the substance.

a rule to measure, but measure between two marks on the scale, estimating tenths of a millimeter by the eye. The distance between the blocks can also be measured by the use of the dividers and the diagonal scale.

(2) Weigh the cylinder, and determine its density as in the preceding exercise. Use a similar tabular form, making two instead of three columns for the dimensions.



Fig. 10.

EXERCISE VII

DENSITY OF A SPHERE

Apparatus.— Same as above. A small sphere of wood or other material.

Operations.— (1) Measure the diameter of the sphere in several different directions, using the square-cut blocks. Estimate by the eye tenths of a millimeter.

(2) Weigh, and determine the density as before.

Use a tabular form similar to that of Exercise V., having only one column for the dimensions.

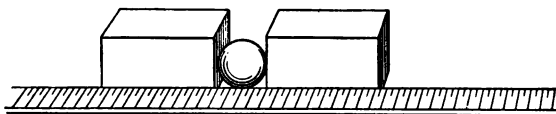


Fig. 11.

CHAPTER II

MECHANICS OF SOLIDS

EXERCISE VIII

ELASTICITY OF BENDING: LENGTH CONSTANT

Apparatus. — Two blocks about $8 \times 8 \times 5$ cm. having thin strips of brass set in them for knife-edge supports. Another block with a short scale attached, graduated in

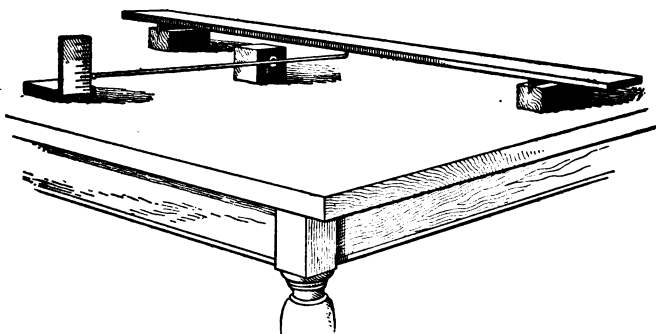


Fig. 12.

millimeters. Another block, to which is attached a lever of aluminum wire about 30 cm. long, the short end being bent up at right angles (Fig. 12). A meter-stick. A set of metric weights. A bar of wood about $100 \times 2.5 \times 1$ cm.

Operations. — (1) Place the two knife-edge supports 80 or 90 cm. apart and about 30 cm. back from the edge of the

table. Lay the bar upon them and the meter-stick beside it, having the knife-edges at right angles to the bar. Place the block with the lever so that the short end of the lever shall touch the under side of the bar at a point midway between the knife-edges, the lever extending toward the edge of the table at right angles to the bar. Place the block with the scale at the end of the long arm of the lever so that the movements of the bar magnified by the lever can be measured on the scale.

(2) See that the blocks do not rock on the table nor the bar on the knife-edges. Everything should be firm before any readings are taken.

(3) Read the position of the lever on the scale, avoiding parallax and estimating tenths of millimeters.

(4) Place on the center of the bar 100 g., and read the position of the lever again. Then remove the weight and again take the position of the lever without any load.

(5) Repeat, using 200, 300, 400, 500 g., always reading and recording the position of the lever both before and after using each load.

Tabulate the data as follows:—

Length of Bar.	Lever Reading without Load.	Average without Load.	Reading with Load.	Deflection or D .	Load or L .	$\frac{D}{L}$
$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$

NOTE. — It is well to wait a moment after removing the weight from the bar before taking the reading, to allow the bar to fully recover.

(6) Draw your conclusion from the last column. Also show the relation between elasticity and deflection.

(7) Taking the load and the deflection as co-ordinates, represent their relation graphically.

Does this exercise afford an illustration of Hooke's law?

EXERCISE IX

ELASTICITY OF BENDING: LENGTH VARIABLE

Apparatus. — The same as for Exercise VIII.

Operations. — (1) Proceed as in the preceding exercise, except that the same load, 500 g., is to be used with different lengths of the bar. Starting with the knife-edges 50 cm. apart, try several lengths up to 80 or 90 cm.

(2) Repeat with 400 g.

Tabulate the data as follows: —

Load.	Lever Reading without Load.	Average without Load.	Reading with Load.	Deflection or D .	Length or L .	$\frac{D}{L}$	$\frac{D}{L^2}$	$\frac{D}{L^3}$
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$

In your conclusion discuss the meaning of the last three columns.

Using first the deflection and the length as co-ordinates, plot a curve showing graphically the relation existing between them; then use the deflection and the square of the length and plot the curve, then the cube of the length. Plot all three curves on the same sheet.

EXERCISE X

COMPOSITION OF CONCURRING FORCES

Apparatus. — Three spring-balances. Two pieces of fish-line. Three pieces of wood about $12 \times 5 \times 2.5$ cm., each having a nail projecting from its upper surface near one end. Three clamps.

Operations. — (1) Connect the hooks (Fig. 13) of two of the balances by a cord 50 to 60 cm. long, having first passed it through a loop in the end of another cord 20 to 30 cm. long. Attach this shorter string to the hook of the third balance.

(2) Place the balances thus connected backs down on the table, passing the rings of the first two over nails driven in the table 30 to 50 cm. apart, or over nails in the small boards clamped to the table.

If the indexes of the balances are not at zero when in this position, allowance must be made for their displacement in all future readings.

(3) Now pull the third balance toward the opposite side of the table until each balance registers several units, but see that none of them is stretched to its full extent.

(4) Place the note-book or a sheet of paper under the junction of the cords, and draw lines from this junction just beneath and parallel to each cord. Success in this experiment depends largely upon the accuracy and care with which these lines are drawn. Secure the note-book by weights or the paper by pins, and use a pencil with a fine point and a thin-edged ruler.

(5) Read each balance with great care, and record the force denoted by it upon the line running toward the balance from which the reading is taken.

Complete the exercise at home. In writing the remainder

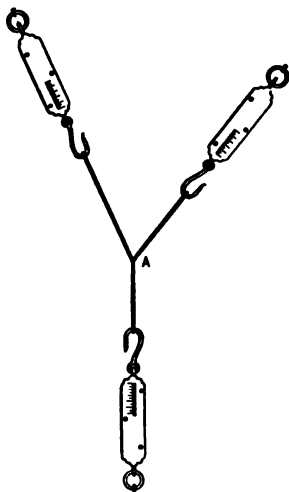


FIG. 13.

of the exercise, the student should observe strictly the order indicated in the following notes and questions:—

(6) Designate the junction of the lines by A and the direction of the forces by arrow-heads.

(7) Lay off from A distances to represent the magnitudes of the forces recorded on the lines, indicating them by B , C , and D .

(8) Extend any one of the lines from A an equal distance in the opposite direction, and designate its extremity by E .

(9) What is the force opposite to AE called with reference to the other two forces? Why? (See C. & C., p. 36.)

(10) What is the force AE called with reference to its two adjacent forces? Why? (See C. & C., p. 36.)

(11) Connect the point E with the extremities of the distances laid off on the two adjacent lines, and measure the opposite sides of the figure formed. What is the figure? What part of that figure is the line AE ?

EXERCISE XI

COMPOSITION OF PARALLEL FORCES

FIRST METHOD

References.—L., pp. 110–113.

Apparatus.—Two 64 oz. spring-balances. A bar of wood about 2.5 cm. square and 48 cm. long, to each end of which is fastened a thin strip of brass with a hole in it for the insertion of the hook of the balance. A mass of iron or lead weighing 2 or 3 lb. A frame or other means for supporting the balances (Fig. 14).

Operations.—(1) Arrange the apparatus, draw a diagram of it, and letter it according to the figure.

(2) Remove the weight F from the bar, and note and record the positions of the indexes of the balances. Sub-

tract these readings from all subsequent readings of A and B before recording them. Why?

(3) By one of the balances ascertain the exact weight of the mass of iron or lead.

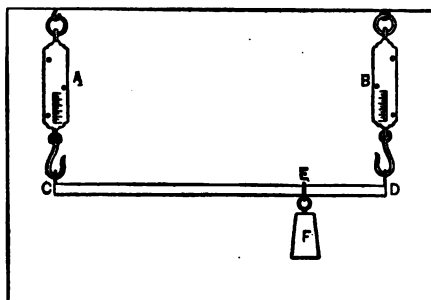


Fig. 14.

(4) Attach the weight F to the bar by a wire or cord; and placing it at different positions along the bar, measure the distances CE and DE , and note the forces indicated by A and B for each position of F .

Tabulate the data as follows:—

F .	A .	B .	CE .	DE .	$A+B$.	$A \times CE$.	$B \times DE$.	$A \times CD$.	$F \times DE$.	$B \times CD$.	$F \times CE$.
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$

(5) What is the force F with reference to the two forces A and B ?

Examine the numbers of the first line of the table. How many sets of equal, or nearly equal, numbers are there? Do these same equalities appear in all of the other lines of the table? If so, write equations to express them, using the letters at the tops of the columns. Convert as many of these equations as you can into proportions. Inferences.

Taking each of the points C , E , and D , in succession, as a fulcrum, show how the three classes of levers are represented. Is the law of the lever verified by any of the equations or proportions?

By the term **moment of a force** is meant the importance of a force in producing rotation about an axis. It is measured by the product of the force into the perpendicular distance between its line of direction and the axis of rotation. For example, the moment of the force A , with respect to E as an axis, is $A \times CE$. The moments tending to produce rotation in a clockwise direction are called **positive**, and those of an opposite effect, **negative**.

Taking in succession each of the points C , E , and D , as an axis, point out the positive and negative moments in the above equations and find the algebraic sum of the moments of the forces A , B , and F in each separate case.

What does the experiment teach as to the sum of the moments acting on a body so as to produce rest?

SECOND METHOD

More accurate results are possible if two Jolly balances are substituted for the spring-balances used above. Use springs made of No. 20 wire having a modulus of about 5 g., and a light bar to connect them 62 cm. long and 1 cm. square. Place hooks in the bar just 60 cm. apart, to which the balance springs can be attached, and divide the rod into spaces of 3 cm. each. Use a small weight F upon the rod, say 20 or 50 g.

Operations. — (1) Determine the modulus of each spring as in Exercise IV.

(2) Take the index readings with no load on the bar for the zero readings.

(3) Place the weight F at the middle of the bar, and take the readings again.

(4) Move the weight 3 cm. and take the readings again, continuing this until the weight is 12 cm. from the end.

Use the following tabular form for A and a similar one for B :—

F -----						
Modulus of A -----						
Zero Reading for A -----						
Index Reading.	Elongation.	A Found.	A Computed.	Difference.	CE .	DE .
$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$

Assuming that the law is known, the values of A and B can be computed and compared with those found. After the data is obtained as described above, construct a third table, like that given in the first method, and work up the data in the same way as in that method.

EXERCISE XII

CENTER OF GRAVITY

Apparatus.—A meter-stick having a small round-headed screw driven into its zero end, the head of the screw projecting sufficiently to allow a thread between it and the meter-stick. A sharp-edged support, or one of the knife-edge blocks used in Exercise VIII., to be used as a fulcrum. A balance and a set of weights.

Operations.—(1) Weigh the meter-stick. Designate this quantity by P in the table.

(2) Set the fulcrum near the end of the table and balance the meter-stick upon it, the edge of the stick resting on the fulcrum. Note the point on the meter-stick just above the fulcrum, designating it by G in the table. A point just above this will be the center of gravity of the ruler.

(3) Suspend by a thread from the screw in the end of the stick a 100 g. weight, and balance the ruler again, designating the point just above the fulcrum by F in the table. Repeat the operation with other weights, as 200 g., 500 g., etc., designating the weights by M in the table.

(4) Designate the end of the ruler where the weight is attached by A , and note the distances AF and GF in each case.

Record the data as follows:—

P -----				G -----		
M .	F .	AF .	GF .	$AF \times M$.	$GF \times P$	Error.
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	1	$\frac{1}{2}$

By what moment is the moment of M about the point F balanced in each case? Does the ruler or lever act as if its weight were concentrated at a point? If so, at what point?

EXERCISE XIII

UNIFORMLY ACCELERATED MOTION

Apparatus.—A triangular standard about 1.25 m. high (Fig. 15). The rods CD , EF , and GH are of iron about 2 cm. in diameter, and the rod ce of brass about 0.5 cm. in diameter. WW is a weight about 50 cm. long that slides

freely up and down the central rod *ce*. This weight is shown in section in Fig. 16. It consists of three pieces of iron 6 cm. wide, 50 cm. long, and 3 mm. thick, fastened to two triangular pieces of brass 4 cm. on a side. A wheel *M*, 12 or 15 cm. in diameter and having a heavy rim, is supported in the frame *AB*. This wheel should be turned true and be pivoted so as to turn freely, but with very little lost motion. A small sharp knife *k* projects through the rim of the wheel 1 or 2 mm. The frame *AB* turns about the rod *CD* as an axis. A spool of stout linen thread is placed on the screw *b*.

Some strips of thin cardboard about 3 cm. wide and 50 cm. long. A stout cord about 1.5 m. long.

Operations.—(1) Fasten a strip of cardboard on the weight *WW* by a rubber band so that its edge shall project beyond the edge of the weight about 5 mm.

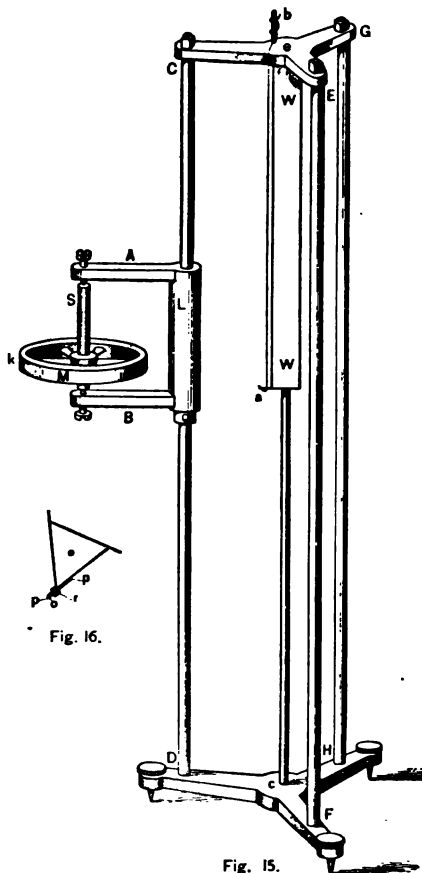


Fig. 16.

Fig. 15.

(2) Support the weight WW in the position shown in the figure by tying the end of the thread from the spool at b to the pin a , and fastening the spool by tightening the screw. The thread should be near the outer edge of the cardboard and parallel with it. Figure 16 represents a cross-section of the weight WW , pp the cardboard, r the rubber band, and o the thread supporting the weight.

(3) Wind the stout cord about the shaft S , and by pulling it off set the wheel in rapid rotation.

(4) While the wheel is rotating, turn the frame AB on the axis CD , so that the rim of the wheel shall almost touch the edge of the cardboard. (A stop, not shown on the figure, extends out from the rod EF , against which the frame AB is pressed to bring it to the right position.)

At the first revolution of the wheel after it is brought into position, the knife k cuts the thread, at the same time marking the cardboard, and liberates the weight. At each succeeding revolution, as the weight descends, it cuts a mark on the edge of the cardboard. It thus marks the position of the weight at the end of equal intervals of time, since the wheel, during the short interval required for the weight to fall, rotates in nearly equal times.

(5) Remove the cardboard from the weight and measure with as great accuracy as possible the distances from the first, or lower, mark to each of the others. Designate these distances by S in the table.

(6) Compute or measure the distance from each mark to the next; that is, the distance traversed during each interval of time. Designate these distances by S' .

The spaces between the marks numbered from the first will correspond to the intervals of time. Designate these by T .

From the formula $a = \frac{2S}{T^2}$ compute the value of a for each value of S .

Find the average value of a .

From this average value of a and by the use of the formula $S = \frac{1}{2} a T^2$ compute the value for S in each case; and by the formula $S' = \frac{1}{2} a (2 T - 1)$ the value for S' in each case. Place the differences between the computed and the measured values in appropriate columns.

What is the relation between S and T^2 , as shown by the values found for a ? Represent this relation graphically, taking the squares of the times for the abscissas, and the total spaces traversed for ordinates.

How does the value of a compare with that of S for the first interval of time?

By the formula $V = aT$ compute the value of V in each case. Use the following tabular form:—

T .	S Measured.	S Computed.	Differ- ences.	S' Measured.	S' Computed.	Differ- ences.	A .	V .
$\frac{1}{2}$	1	1	1	1	1	1	$\frac{1}{2}$	$\frac{1}{2}$

NOTE.—This apparatus is the invention of Mr. H. M. Randall, of the High School of Saginaw, Mich., and was first exhibited by him at a meeting of the Michigan Schoolmasters' Club in November, 1895.

EXERCISE XIV

THE PENDULUM: THE LAW OF LENGTH

Apparatus.—Some fine thread. A large bullet. A watch or a clock with a second hand. Calipers. A clamp with square jaws (Fig. 17). Why should the jaws of the clamp be square?

Operations.—(1) Measure the diameter of the bullet with the calipers.

(2) Fasten a piece of thread, about 2 m. long, to the bullet and suspend it by the clamp from a bracket on the wall. This may be considered a simple pendulum, but it is not truly such, as the bullet has size and the thread has weight. The center of the bullet may be considered the center of oscillation, and therefore the true length of the pendulum will be the distance from the lower edge of the clamp to the center of the bullet.

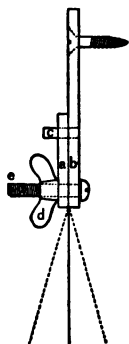


Fig. 17.

(3) Adjust the length of the pendulum to about 1.5 or 2 m., and find its exact length by measuring the thread from the edge of the clamp to the top of the bullet, and adding to this the radius of the bullet. Do not attempt to make a pendulum of any particular length. Why?

(4) Find the time required for 100 half-vibrations, one pupil counting the vibrations while the other notes the time of beginning and ending the count.

Method of Taking Time.—First learn to express time properly. For example, instead of recording the time of beginning as 15 min. and 12 sec. of 10 o'clock, write 9 hr. 44 min. 48 sec.

To observe the vibrations, draw a heavy vertical line on the wall just back of the pendulum, and stand so that the pendulum and the mark on the wall are in line, the pendulum being at rest.

Set the pendulum swinging through a small arc, not more than 6° . Let one fix his attention on the watch or clock, and the other on the pendulum. The latter should count the vibrations aloud, beginning with the word *zero*, and counting each swing just at the moment the thread passes the mark on the wall. The former must note the exact time the word *zero* is called; and again, later, the exact

time the 100th swing is called. The difference between these two times will be the time of 100 half-vibrations.

The passage of the thread over the line at the exact instant the clock ticks is called a **coincidence**. If a clock with a sounder is used, the person watching the pendulum should listen to the sounder and begin and end the count at a coincidence. This will avoid the estimating of the fraction of a second at the end of a count. In order to end the count at a coincidence it will be necessary usually to take a few more than 100 vibrations instead of stopping at the 100th swing.

(5) Make four or five determinations of the time required for 100 vibrations for the given length of pendulum, and find the average time of one vibration as the **period** of a pendulum of this length.

(6) In like manner determine the period of the pendulum having several different lengths, varying from 0.5 m. to 2 m.

The arc through which the pendulum swings should not exceed one-tenth of the length of the pendulum, since the law which you are studying is not true for arcs greater than 6° . If the chord of the arc of vibration equals the radius or the length of the pendulum, then the arc is 60° ; and if the chord of the arc is one-tenth of the radius, the arc will be a rough approximation of 6° . What is one-half of this arc called?

Record the data as follows: —

DIAMETER OF BULLET -----								
Length of Pendulum.	Time of Beginning.	Time of Ending.	Whole Time.	No. of Vibrations.	Time of 1 Vibration.	Square Root of Length.	Average Time for each Length.	$\frac{\text{Av. Time}}{\sqrt{\text{Length}}}$
$\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$

In the sixth column find the average time of one vibration for each length taken, and in the last column place the quotient of this average time divided by the square root of the length.

Calculate by the law derived from the above table, from any length taken and the average time found for that length, the length of a pendulum that will vibrate once a second.

Also find the average of the numbers in the last column, and, placing it equal to $\frac{1}{\sqrt{x}}$, find the value of x . What does x represent?

Also from the value of x just found, and by the formula $T = \pi \sqrt{\frac{L}{g}}$, find the value of g .

Taking the average time found for each length and the square root of each length, plot a line showing their relation to each other.

EXERCISE XV

THE PENDULUM: LENGTH OF ARC

Apparatus. — Same as for Exercise XIV.

Operations. — This experiment should be completed at one session unless it is certain that the pendulum will not be disturbed.

(1) Make a pendulum about one meter long. Its exact length is not important, but the same length must be preserved throughout the experiment.

(2) Determine the time required for one vibration, as in the preceding experiment, the arc through which the pendulum swings being less than 6° .

(3) Start the pendulum swinging through an arc of about 60° , and determine the time for one vibration, as before.

(4) Determine the period, the arc being about 30° .

It is not sufficient in any case to find the time of one vibration by taking the time for 100 vibrations just once, but the average of at least three determinations should be taken. Better results will be obtained by taking the time required for 300 or 500 vibrations instead of 100.

The number of degrees in the arc can be determined approximately by comparing the chord of the arc with the length of the pendulum, remembering that when the chord of the arc equals the length of the pendulum the arc is 60° . Exact measurements of the arcs are not required.

Tabulate the data as follows:—

Length of Arc.	Time of Beginning.	Time of Ending.	Time of 100 Vibrations.	Time of 1 Vibration.
$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	1	1

Find the average time for all arcs less than 6° ; for all arcs about 30° ; for all arcs about 60° ; and compare the times of these three averages.

EXERCISE XVI

THE INCLINED PLANE

References.—L., arts. 74–94; W., pp. 115, 116; H. & B., 157.

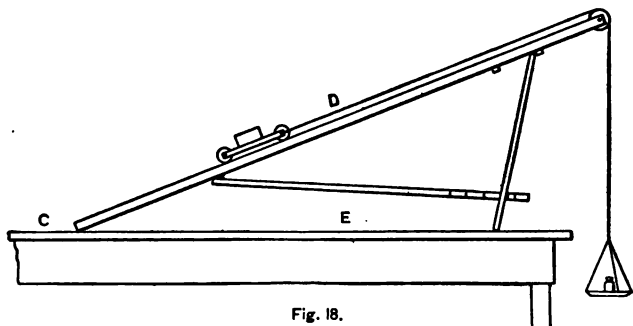
Apparatus.—A smooth board about $16 \times 125 \times 2.5$ cm. A small car (a roller skate will do). A small pulley that can be clamped to, or screwed into, one end of the board. A stout cord about 1 m. long (a braided fish-line is best). A scale-pan about 15 cm. in diameter. A set of metric weights. Some blocks or other means for supporting one

end of the board when raised above the table to form an inclined plane (Fig. 18). A platform balance. A mass of lead or iron of about 1 kg.

Operations. — (1) Place the board upon the table, having the end with the pulley raised 40 to 50 cm. above the table and projecting slightly beyond the end of the table.

(2) Find the weight of the scale-pan, then of the car and the lead mass together by means of the platform balance.

(3) Connect the car and the scale-pan by a cord about 1 m. long. Place the car upon the plane and pass the cord over



the pulley, thus suspending the scale-pan so that it can rise and fall freely without touching the table while the car rolls up and down the plane. The pulley should be so placed that the cord shall be parallel to the plane of the board.

(4) Place the lead mass upon the car, and determine by several trials what weight in the pan is necessary to pull the car up the plane at a uniform speed *after it is started*. Record the results of three different trials, adding in the weight of the pan each time.

(5) Likewise find what weight in the pan will allow the car to roll down the plane at a uniform speed *after it is started*.

(6) Designate the intersection of the plane of the board with the plane of the table by C . This point may be found by placing the edge of a ruler on the board and sliding it down until its end just touches the table. From this point C , measure off on the plane a distance of 50 cm., designating the point reached on the plane by D . From D , by means of a square and a rule, measure the vertical distance to the table, designating this line by DE . DE will be the vertical rise of the car when it goes up the plane 50 cm., if the table is level. What is the vertical distance traversed by the pan when the car rises vertically a distance equal to DE ?

(7) Draw in your note-book a diagram in which the distances CD , DE , and CE , and the angle at C , shall be accurately represented; and record on CD and DE the distances they represent.

Record the data as follows:—

Weight of the pan -----

Weight of the car and its load -----

Vertical rise of car to every 50 cm., along the plane -----

Trials.	First.	Second.	Third.	Average.
Pan plus weights, car going up				
Pan plus weights, car going down				
One-half the sum of the averages -----				
One-half the difference of the averages (friction) -----				

According to the first law of motion, what is true of the forces acting on a body moving with uniform velocity?

One-half of the sum of the averages in the above table would be the force necessary to balance the car, if there were no friction.

One-half their difference will be the amount of the friction.

The inclined plane is one of the six simple machines. Call the car and its load the weight, and the pan and its load the power. According to the law of machines, the work done on the weight (RS) must equal the work done by the power (FS). Show that it is true in this case, using the data in your table.

Draw on your diagram, which should have the lines CD and DE in the same proportion as the distances they represent, a line to represent the weight of the car and its load, selecting a suitable unit of length to represent a unit of weight. Resolve this force into two forces, one lying in CD and the other perpendicular to CD . Determine the value of these components by measurement, and compare one of them with the power.

CHAPTER III

MECHANICS OF FLUIDS

EXERCISE XVII

DOWNWARD PRESSURE IN LIQUIDS

Apparatus.—A cylindrical glass jar about 8 cm. in diameter and 40 cm. deep, having a paper scale pasted down its side. This scale can be cut from cross-section paper ruled in millimeters or in twentieths of an inch. A glass tube about 75 cm. long and 4 mm. inside diameter, bent as shown in Fig. 19, the tube being filled with mercury at the bend to a depth of about 2 cm. A clamp for holding the tube, consisting of two pieces of wood about $15 \times 4 \times 2$ cm., each piece having a shallow groove across the middle of one side. These pieces are held together by a rubber band, the tube being placed in the groove between them.

Operations.—(1) The jar being nearly full of water, place the tube in the clamp and support it in the jar by resting the clamp across the top of the jar. The tube can now be moved easily up and down and will be held at any desired position.

(2) With the mouth of the tube about 15 cm. below the surface of the water, note the position of the sur-



Fig. 19.

face of the water on the scale. To one looking obliquely upward (Fig. 20) at this surface, it appears like a brilliant mirror. Raise the eye gradually until the line of sight

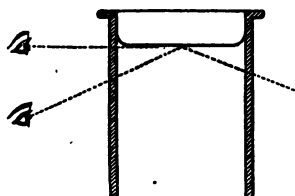


Fig. 20.

just grazes the mirror-like surface; and then note its position on the scale.

(3) Note the height of the mercury surface in the short arm of the tube; that is, the point where the mercury and water meet in the tube. All

the air must be removed from the short arm of the tube.

This measurement can be taken best by wrapping a band of paper with a straight edge about the jar and sliding it down until its upper edge is on a level with the mercury. Sight through the water to the edge of the paper on the opposite side. The paper may be held in place by a rubber band.

(4) In the same manner observe the height of the mercury in the long arm of the tube, *estimating tenths* of a division in this and all the other measurements taken.

(5) Move the tube down a few centimeters and repeat the above measurements, not omitting the first one, the surface of the water in the jar. Take about ten sets of measurements.

Record the data as follows:—

Surface of Water.	Mercury in Short Arm.	Mercury in Long Arm.	Depth of Water.	Elevation of Mercury.	Elevation per Unit of Depth.
1	1	1	1	1	1

The quantity in the fourth column is the depth of water exerting pressure on the mercury, and is found by taking the difference between the quantities in the first two columns.

EXERCISE XVIII

LATERAL PRESSURE IN LIQUIDS

Apparatus.— Same as for Exercise XVII. except that the tube is bent so as to open laterally, as shown in Fig. 21.

Operations.— (1) The procedure is, in general, the same as in the preceding exercise. In this case, however, the water and the mercury must not come together in the tube. The pressure of the water will be transmitted to the mercury by the inclosed air.

One measurement more than was taken in that exercise will be necessary,— the depth of the center of the lateral opening. To do this, measure to the upper edge of this arm and then add to this the radius of the tube, its diameter having been previously found by calipers.

The table for this exercise requires one additional column for the depth of the lateral opening.



Fig. 21.

EXERCISE XIX

UPWARD PRESSURE IN LIQUIDS

Apparatus.— Same as for the preceding exercise except that the tube opens downward, as shown in Fig. 22.

Operations.— (1) Proceed as in the last exercise; but instead of finding the position of the mouth of



Fig. 22.

the tube, take that of the point where the air and water meet in the tube.

Use a table similar to that of the last exercise.

In the last three exercises, using the pressures and the depths as co-ordinates, show graphically the relation between them.

What does a comparison of the last column in each of the tables of the last three exercises with one another teach?

Do you see how the results of these exercises may be used in comparing the density of mercury with that of water? Find the average of the last column in each of the three tables.

EXERCISE XX

READING THE BAROMETER

Apparatus. — A barometer with a thermometer attached. A thermometer outside the building.

Operations. — (1) Read the thermometer attached to the barometer at once, before it is influenced by the body of the observer.

(2) Tap the instrument gently near the upper level of the mercury to counteract the adhesion of the mercury to the glass, which sometimes prevents small movements of the mercury.

(3) Adjust the mercury in the cistern to its proper level. To do this, turn the screw *O* at the bottom of the instrument until the mercury at *q* (Fig. 23) just touches the ivory pointer *h*. Why is this adjustment necessary?

(4) Adjust the vernier to the top of the mercury by turning the milled head *D* (Fig. 24). Its lower edge should be tangent to the top of the mercury, so that a white back-

ground can be seen on either side but not at the center of the mercury surface. Read the height in both inches and centimeters.

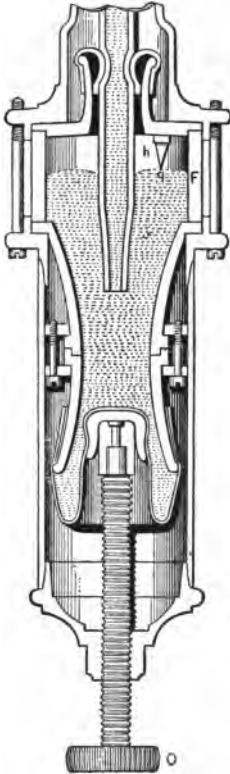


Fig. 23.

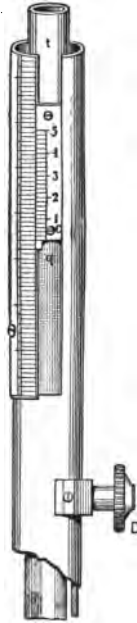


Fig. 24.

- (5) Take the temperature by the outside thermometer.
- (6) In the Appendix, p. 173, find the correction for temperature, using that found by the thermometer on the instrument. If the temperature is above 32 F., subtract this

correction; otherwise add it. Why? (What effect does temperature have on the density of mercury?)

(7) In the Appendix, pp. 174-177, find the correction for elevation above sea level, using the temperature given by the outside thermometer. Add this. Why? (Ascertain the elevation from the instructor.)

(8) Make observations for several consecutive days at the same hour of the day, and tabulate the results as follows:—

Date.	Hour.	Temperature of Barometer.	Temperature Outside.	Height in Inches.	Height in Centimeters.	Correction for Temperature.	Correction for Elevation.	Corrected Height.	United States Report.
$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$

(9) Obtain the United States Signal Service report for the same days at the nearest station, and place them in the last column. Compare your results with them, and explain any discrepancy if you can.

EXERCISE XXI

COMPRESSIBILITY OF GASES: BOYLE'S LAW

References. — G. & S., pp. 205-208.

Apparatus. — A barometer. A standard (shown in section, Fig. 26) about 2.2 m. tall, on the front of which is a scale formed by two meter-sticks placed end to end. Two glass tubes, one on each side of the scale, are supported by carriers that slide freely up and down the standard and can be fastened at any desired position by pins. One of these tubes *B* (Fig. 25) has an iron cap (Fig. 27) that can be closed air-

tight by its top, which screws on. (Fig. 28 shows a vertical section of this cap.) The two tubes *A* and *B* are connected at their lower ends by a thick-walled rubber tube about 7 ft. long. The whole contains sufficient mercury to fill the rubber tube and the glass tubes about halfway up. The standard should be attached to a heavy baseboard, or, better, firmly fastened to the wall.

Operations. — (1) Adjust the tubes so that when the mercury in both is at the same level, the air column in *B* shall be about 15 cm. long. Measure the distance from the top of *B* to the lower edge (*E*, Fig. 27) of the iron cap; then close the tube air-tight by screwing on the top. As it is rather difficult to make this air-tight, it is better for the instructor to make this adjustment and measurement once for all; and then the screw top need not be disturbed by the pupil. The length of this air column will thereafter be found by adding the above measurement to the length of the air column below it.

Explanation. — When the mercury in *A* and *B* is at the same level, the air in *B* is under the pressure of one atmosphere, which is found by the barometer. Why?

When the mercury in *A* is higher than in *B*, the pressure on the air in *B* is one atmosphere plus the difference between them. Why?

When the mercury in *A* is lower than in *B*, the pressure is one atmosphere minus the difference in level between them. Why?

By moving *A* and *B* up and down, the level in *A* can be made to range from about 40 cm. below *B* to 150 cm. above it. What happens to the air in *B*, when

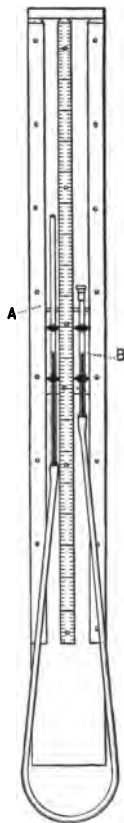


Fig. 25.

A is raised above it? When A is placed below it? Why?

For any one position of A and B the following measurements must be taken:—

(1) Read the barometer in centimeters, or in inches and reduce to centimeters, not correcting for temperature. Represented by C in table.



Fig. 26.



Fig. 27.

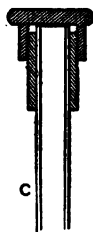


Fig. 28.

(2) The height of mercury in B . Represented by B in table.

(3) The height of mercury in A . Represented by A in table.

(4) The position of the lower edge of the iron cap, represented by E in the table. Add to this the length of the iron cap found before the top of the cap was screwed on. This will give the top of the air column B .

Make from ten to twenty sets of measurements, having the level of A range from about 40 cm. below B to 150 cm. above it.

Let P equal the total pressure on the air in B , and V the volume of the air in B . If 1 cm. in length of the tube B be taken as a *unit volume*, then the volume of the air in B will be measured by the length of this air column in centimeters. Under what condition would it express the volume in cubic centimeters?

Record the data as follows:—

LENGTH OF IRON CAP. = L .								
C .	A .	B .	E .	$E + L$.	$A - B$.	P .	V .	$P \times V$.
$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$

Remarks.—It will save time to move the tube B once only during the experiment. First, place B about on a level with the eye and take the observations with A below B . Then place B near the bottom of the instrument and take the observations with A above B .

When A is very high above B , the rubber tube is likely to stretch while the measurements are being taken. This causes an error. To avoid it as much as possible, take the readings as quickly as possible, taking B first.

Using the pressures and the volumes as co-ordinates, plot a curve showing graphically the relation between them.

EXERCISE XXII

DENSITY OF WATER

References.—S. & G., Vol. I., pp. 106, 107.

Apparatus.—A burette. A small beaker. A balance. A thermometer.

Operations.—(1) See that the beaker is clean and dry, and then weigh it.

(2) Measure out in the beaker from 20 to 40 c.c. of distilled water by means of a burette.

To do this, fill the burette with water, carefully wiping off any on the outside of the instrument. Then allow some

water to run out of the burette by the stop-cock into a waste dish until the surface of the water is below the zero at the top and all the air bubbles are driven out of the lower end of the burette. Note with great care the position of the surface of the water on the scale, and then allow the water to be measured to flow into the beaker. Read again the amount of water in the burette; and by subtracting the first reading from the last obtain the volume of water in the beaker.

(3) Weigh the beaker and water and then take its temperature (see note in Exercise XXIX. in regard to reading the thermometer). Stir the water carefully with the thermometer until the mercury is stationary before reading the temperature.

(4) Find the weight of the water and calculate its density as in Exercise V.

Record the data as follows: —

Weight of empty beaker	
Weight of beaker and water	
Weight of water taken	
Temperature of the water	
First reading of the burette	
Second reading of the burette	
Volume of water taken	
Density of water found	
Density of water at given temperature (see Table IV., p. 171)	
Error	Percentage of error

If time permits, the average of several determinations should be found and then the error and the percentage determined.

EXERCISE XXIII

BUOYANT FORCE: THE PRINCIPLE OF ARCHIMEDES

Apparatus.—A beaker filled with distilled water. A Jolly balance. A piece of fine waxed thread. The metallic cylinder whose density was determined in Exercise VI.

Operations.—(1) Taking the cylinder whose weight and volume were found in Exercise VI., find its weight while it is immersed in distilled water. To do this, either suspend the cylinder from the under side of the balance pan by a thread; or if the balance has a pan of glass, place it in that. In the latter case the index reading with no load in the pan must be taken with the pan in water also. Why?

Record the data as follows:—

Weight of the cylinder in air
Weight of the cylinder in water
Loss of weight in water
Volume of the cylinder

(2) What volume of water was displaced by the cylinder?

(3) What weight of water was displaced by the cylinder? Why? See exercises VI and XXII.

(4) How does the loss of weight in water compare with the weight of the water displaced?

(5) How many times denser is the cylinder than water, comparing the results of Exercise VI. with this?

The answer to the last question will be the **specific gravity** of the substance composing the cylinder. What is specific gravity?

(6) How can the volume of the cylinder be determined

from the data of this exercise and the preceding exercise?

Compare the volume so obtained with that obtained in Exercise VI., and determine the error and the percentage of error assuming this to be correct.

EXERCISE XXIV

SPECIFIC GRAVITY OF SOLIDS DENSER THAN WATER

Apparatus. — A Jolly balance or a beam balance. A glass of distilled water. A piece of waxed thread. A piece of brass, or other substance, whose specific gravity is to be determined.

Operations. — (1) Weigh the solid in air.

(2) Weigh the solid while it is immersed in distilled water. To do this, either suspend it by a thread from the under side of the balance pan, or if the balance has two pans, one above the other, place the solid in the lower pan to weigh it in water. In the latter case the lower pan should be immersed in water to about the same depth *throughout the entire experiment.*

From its weight in air and in water compute the density of the solid and compare with that of water in accordance with the principles of the last exercise.

Remarks. — To correct for the error due to the fact that the water used is not at 4° C., multiply the density found by the density of water at the temperature at which it was used. This may be found in Table IV., on p. 171. To find the amount of the error of your results, compare them with those given on p. 170.

When a Jolly balance is used, the elongations alone of the spring may be used, the modulus of the spring not

being considered. Why? Thus in the above exercise, if a represents the index reading with no load, b the index reading with the load in air, and c that with the load in water, then $(b - a)$ divided by $(b - c)$ will equal the specific gravity of the substance. Explain.

How can specific gravity be reduced to density, whether the density be expressed in the metric or in English units? The density of water is 0.577 oz. per cubic inch. Reduce the specific gravities found to densities in both systems.

Record the data as follows:—

a .	b .	c .	Specific Gravity.	Density in Grams per Cubic Centimeter.	Density in Ounces per Cubic Inch.	Error.
$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	1	1	1	1

EXERCISE XXV

SPECIFIC GRAVITY OF SOLIDS LESS DENSE THAN WATER

Apparatus.—A Jolly balance or a beam balance. A small cylinder of brass to be used as a sinker, having a sharp needle-like point at one end and a hook at the other (Fig. 29). A thermometer. Distilled water. A piece of wax, or other substance lighter than water, whose specific gravity is to be found.

Operations.—(1) Attach the cylinder to the under side of the balance pan by a fine wire about 5 cm. long, the point of the cylinder being down.

(2) Immerse the cylinder in water, and keep it immersed throughout the entire exercise.

(3) If a beam balance is used, counterpoise the cylinder. If a Jolly balance is used, take the index reading with the cylinder in water.

(4) Place the wax in the scale-pan above the cylinder and weigh it, or take the index reading.

(5) Fasten the wax to the cylinder by thrusting the point of the cylinder into it, and immerse wax and cylinder in water.

(6) If a beam balance is used, add weights to the pan to which the cylinder is attached until equilibrium is restored. The weights

added will equal the weight of the water displaced by the wax. If a Jolly balance is used, take the index reading again.

The remarks of the last exercise in regard to correction for temperature and method of calculation will apply to

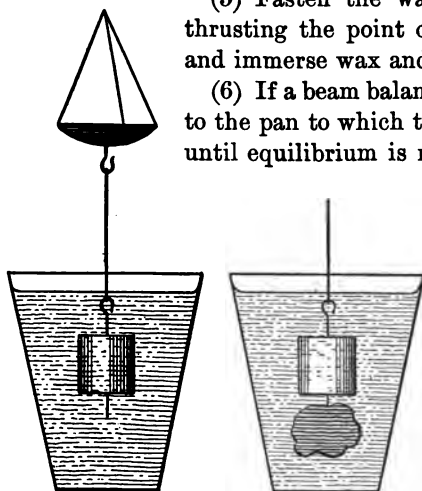


Fig. 29.

this exercise. In fact, with the Jolly balance the operations and calculations are exactly the same as in the last exercise.

When a beam balance is used, the weight in air divided by the weights added to restore the equilibrium will give the specific gravity. Why?

Use the same tabular form as for the last exercise.

EXERCISE XXVI

SPECIFIC GRAVITY OF LIQUIDS BY WEIGHING A SOLID
IN THEM

Apparatus. — A Jolly balance or a beam balance. A piece of a glass rod or a glass stopper for a sinker. A liquid whose specific gravity is to be determined, such as glycerine, benzine, alcohol, kerosene, or sulphuric acid. A thermometer.

A. WITH A BEAM BALANCE

Operations. — (1) Find the weight of the sinker in air.

(2) Find the weight of the sinker in water, suspending it by a thread, or if the liquid is an acid, by a platinum wire, from the under side of the balance pan.

(3) Dry the sinker and find its weight in the liquid.

(4) Take the temperature of the water.

B. WITH A JOLLY BALANCE

(1) Take the index reading with the sinker in air.

(2) Take the index reading with the sinker in water.

(3) Take the index reading with the sinker in the liquid.

(4) Take the temperature of the water.

If the liquid and the water have been standing for some time in the same room, the temperature of both may be assumed to be the same without serious error.

Before transferring the sinker from one liquid to another, always wash and dry it carefully.

If a represents the index reading sinker in air, b reading sinker in water, and c sinker in the liquid, then $(a - c)$ divided by $(a - b)$ will give the specific gravity of the liquid. Why?

Correct for temperature as in the preceding exercises.

To what is the loss of weight in water equivalent? the loss in the liquid? Why?

EXERCISE XXVII

SPECIFIC GRAVITY OF LIQUIDS BY MEANS OF A BOTTLE

References.—S. & G., p. 128.

Apparatus.—A balance. A specific gravity bottle. Alcohol. Bellows, to which a glass tube is attached by a rubber tube. A thermometer. A shallow pan containing tepid water. A liquid whose specific gravity is to be determined.

Operations.—(1) See that the bottle is thoroughly clean and dry. In cleaning the bottle, rinse it finally with distilled water and then with alcohol, after which dry it by passing a stream of air through it by means of the bellows and the glass tube. If the air is warmed somewhat by holding the glass tube in the flame of a Bunsen burner, the bottle will be dried more quickly and thoroughly.

(2) Weigh the empty bottle, or take the index reading with the empty bottle in the pan.

(3) Fill the bottle with distilled water. See that no air bubbles remain in the bottle, and that it is full to the top of the stopper.

(4) Have the shallow pan ready with some water in it at about 30° C. Allow the bottle to stand in this for a few minutes, until the water in it has come to some definite temperature, which will be indicated by a thermometer placed in the pan. Record this temperature at the time the bottle is taken from the water. This temperature should be above that of the room, say 25° to 30° C.

(5) Wipe the bottle dry on the outside and weigh it, or take the index reading with it in the Jolly balance pan.

(6) Empty and dry the bottle and fill it with the liquid. Treat this in the same way the bottle full of water was treated, bringing it to the same temperature by adding warm or cold water to the water in the pan, as the case may require, and stirring it thoroughly.

(7) Weigh the bottle full of the liquid, or take the index reading with it in the pan.

(8) Return the liquid to the bottle from which it was taken, and thoroughly cleanse the specific gravity bottle before putting it away.

If a is the index reading for the empty bottle, b for the bottle full of water, and c for the bottle full of the liquid, then $(c - a)$ divided by $(b - a)$ will be the specific gravity of the liquid.

Correct for temperature as in the preceding exercise.

NOTE. — The fact that the bottle does not remain full after being taken from the water is of no consequence. It is due to contraction. Equal volumes are taken at the temperature of the water in the pan.

EXERCISE XXVIII

SPECIFIC GRAVITY OF LIQUIDS BY HARE'S METHOD OF BALANCED COLUMNS

Apparatus. — A “Y” tube, to which two glass tubes about 50 cm. long and 8 mm. in diameter are joined by short pieces of rubber tubing. A rubber tube about 30 cm. long, and closed by a pinch-cock, is attached to the third branch of the “Y” tube. Two tumblers, one containing distilled water and the other the liquid to be tested (see Fig. 30). A thermometer.

Operations.—(1) Support the tubes in a vertical position, with the two glass tubes standing one in each tumbler.

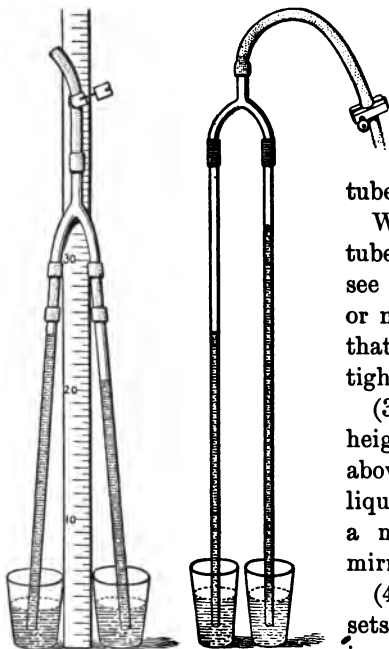


Fig. 30.

(2) Raise the liquids in the tubes to a height of 30 or 40 cm. by a partial exhaustion of the air through the rubber tube, and then close the tube *air-tight* by the clamp.

Watch the liquids in the tubes for a few moments to see whether the liquids fall or not. If they do, it shows that the tube is not closed *air-tight* by the clamp.

(3) Measure the vertical height of the two columns above the surfaces of the liquids in the tumblers, using a meter-stick, or, better, a mirror scale.

(4) Make three different sets of measurements, changing the heights of the columns each time.

(5) Take the temperature of the liquids in the tumblers. Devise a suitable table for the data.

Dividing the height of the water column by the height of the other column will give the specific gravity of the liquid. Why?

Correct for temperature as in the preceding exercise and find the average of the several results.

CHAPTER IV

HEAT

EXERCISE XXIX

TESTING A MERCURY THERMOMETER

Apparatus. — A mercury thermometer. A cup of about 1 l. capacity. A Florence flask of about 1 l. capacity, or, better, a copper or tin dish like that shown in Fig. 31 or "Apparatus A" of the Harvard list. If a flask is used, the heat rising from the flame about the sides of the flask may give rise to a large error. The flask should be set in a large square of asbestos paper. A barometer. An iron tripod or retort stand. A Bunsen burner. Some clean ice or snow.

A. TO TEST THE ACCURACY OF THE FREEZING-POINT MARK

Operations. — (1) Suspend the thermometer in the cup by a clamp so that its freezing-point mark shall be about on a level with the edge of the cup.

(2) Pack about the bulb of the thermometer and its stem, as far up as the freezing-point mark, fine ice chips or snow.

(3) Allow it to stand several minutes until assured that the mercury has become stationary. Then read the position of the mercury, estimating the tenths of a degree. Read it several times. It is not necessary to allow the water to run

out of the cup as fast as the ice melts, as is often done. If plenty of ice is present, better results will be obtained by surrounding the thermometer with water. (Preston's Theory of Heat, p. 106.)

N.B. — In this and all other experiments in which a thermometer is used, it is very important in taking the readings that the *line of sight* shall be perpendicular to the thermometer. In the following experiments in Heat very much depends upon the accuracy with which the readings of the thermometer are taken.

B. TO TEST THE BOILING-POINT MARK (Fig. 31)

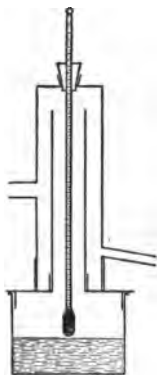


Fig. 31.

Operations. — (1) Fill the flask or basin about one-third full of water, and place it over the flame so that the water shall boil vigorously. Suspend the thermometer so that its bulb shall be 2 or 3 cm. above the boiling water. The stem should be surrounded by the neck of the flask as far up as the boiling-point mark.

(2) When assured by several readings that the mercury has become stationary, record the position of the mercury.

(3) Read the barometer and compute the true boiling-point of water for the given pressure by subtracting 1° C. for every 27 mm. below 76 cm., or 1.07 in. below 29.92 in.; add the correction if the barometer is above 76 cm. or 29.92 in. (See Table IX., p. 178.)

Tabulate as follows: —

Thermometer No.	
Graduation of stem extends from	 to
Observed freezing-point	 Error.....
Barometer	
Computed boiling-point	
Observed boiling-point	 Error.....

If the observed freezing-point is below the mark, or the observed boiling-point below the computed boiling-point, call the correction positive; if above, call it negative.

EXERCISE XXX

COEFFICIENT OF LINEAR EXPANSION

Apparatus.— A brass tube *A*, the expansion of which is to be measured, about 60 cm. long and 0.6 cm. in diameter. Each end of it is plugged with brass and cut off square. It is placed within a tin tube *B*, and projects at each end about 1 mm. beyond the ends of *B* (Fig. 32).

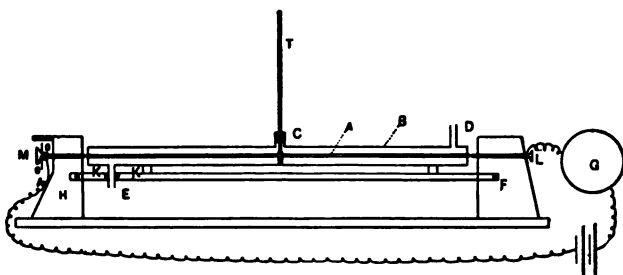


Fig. 32.

The tube *B*, about 4 cm. in diameter, is closed at each end by tin disks soldered to the tube and also to the brass tube. *B* is provided with a tube *C*, about 2 cm. in diameter, for the insertion of a thermometer *T*, and two small tubes *D* and *E*, about 0.5 cm. in diameter, for ingress and egress of steam. The whole is supported in a rack having two upright supports *F* and *H*, through which pass two screws *L* and *M*. These screws are in line with the tube *A*, and one of them, *M*, is a micrometer screw having a

graduated head and a known pitch. The action of this screw is practically the same as that described in Exercise III. The tube *E* passes through a slot in the board *KK*, which prevents the tube *B* from turning about on its axis. The screws *L* and *M* are connected by wires to a battery and a galvanometer which will indicate when both screws *L* and *M* are in contact with the tube *A*. The galvanoscope (Fig. 36) will answer admirably for this experiment, or a telephone receiver, telegraph sounder, or an electric bell may be used. A chemical thermometer. A mirror scale or a meter-stick for measuring the length of *A*. A flask or other vessel containing boiling water so arranged that it can be connected by a rubber tube to *D* to supply steam to the tube *B*.

Operations. — (1) Measure the length of the rod *A* by a mirror scale or a meter-stick, using two square-cut blocks according to the method given in Exercise VI. This measurement should be taken with the rod *A* at the temperature of the room.

(2) Place the thermometer through the cork in *C* so that its bulb shall be at the side of the rod *A*, and leave it there for several minutes, or until assured that the rod and the thermometer are at the same temperature as the air of the room. This may be hastened by connecting a bellows to *D* and forcing air through the tube.

Record the temperature of the rod, taking it with great care.

(3) Place the tube so that *A* is in firm contact with the screw *L*, then turn the screw *M* *carefully until it just comes in contact* with the rod *A*. This contact will be indicated by the galvanometer or other instrument in the circuit. Watch the galvanometer carefully, and *stop turning the screw the instant the needle moves*.

Record the reading of the micrometer head at this contact.

(4) Turn the micrometer screw back one whole revolution

to give room for expansion. Connect the vessel of boiling water by a rubber tube to *D*, and pass steam into the apparatus until steam has issued from the tube *E* for three or four minutes.

Read and record the temperature again.

(5) While the steam is passing through the tube, turn the screw *M* up again until contact occurs as before. The amount of expansion will be obtained by subtracting the first reading from this reading, if the micrometer head is graduated in a clockwise direction. If the graduation is counter-clockwise, subtract this reading from that obtained under paragraph (3).

Make three trials for the same rod and take the average of the results.

Tabulate as follows:—

Trial.	Length.	Temperature.			Micrometer Readings.		Expansion.	Expansion per Degree.
		First.	Last.	Change.	First.	Second.		
$\frac{1}{2}$ 2 etc.	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	1
Average expansion per degree -----								
Expansion per degree per unit length -----								
Accepted coefficient of expansion of -----								
Error ----- Percentage of error -----								

Calculations.— Dividing the expansion per degree by the length of the rod *A*, gives the expansion per unit of length for one degree change of temperature. This constitutes the coefficient of expansion of the substance of the rod.

An error of one centimeter in measuring the length of the rod will affect the final result about the same as the error of one degree in the change of temperature, or an error of one-hundredth of a millimeter in measuring the expansion of the rod; hence it is evident that especial care must be given to the temperature readings and to measurement of the expansion.

EXERCISE XXXI

EXPANSION OF AIR UNDER CONSTANT PRESSURE

Apparatus. — A thermometer. Some ice. A small quantity of mercury. A glass tube about 40 cm. long and 1 mm. internal diameter, closed at one end, and bent at right angles about 5 cm. from the open end. A glass or tin tube, 2.5 or 3 cm. in diameter and 40 cm. long, each end of which is fitted with a two-holed cork (Fig. 33). A flask or other



Fig. 33.

vessel arranged to supply steam. A shallow basin long enough to hold the small glass tube in a horizontal position. There should be a file-mark (*e*, Fig. 33) near the bend on the long arm of the tube. (Good results in this experiment will not be obtained unless the interior of the tube and the mercury are perfectly dry.)

Operations. — (1) Heat the glass tube for about 20 cm. of its length in the flame of a Bunsen burner, and then hold its open end in mercury so that as it cools a filament of mercury about 1 cm. long shall be drawn into the tube. This

filament should be 10 or 15 cm. beyond the file-mark towards the closed end of the tube when the tube is cold.

(2) Measure the distance from the file-mark to the end of the bore at the closed end of the tube.

(3) Place the tube in a horizontal position in a basin and pack pulverized ice about it, having the open end up to keep out the water. Jar the tube gently now and then to facilitate the movement of the mercury, and when the filament has become stationary, measure the distance from the file-mark to the inner end of the mercury filament.

(4) Pass the tube through one of the corks of the large tube and a thermometer through the cork at the other end; then by a rubber tube connect the large tube to a vessel of boiling water and pass steam through it. (See the figure for the proper arrangement.)

Keep the tube in a horizontal position, jarring it now and then to move the mercury, and keep the tube pushed through the cork so that only a portion of the filament is visible. After the mercury becomes stationary, measure again the distance from the file-mark to the inner end of the filament.

(5) Take the temperature of the steam; or instead of using a thermometer, compute the temperature from the barometric pressure as in Exercise XXIX., Part B.

Tabulate as follows:—

Distance from file-mark to closed end of tube	-----
Distance from file-mark to filament end, tube in ice	-----
Distance from file-mark to filament end, tube in steam	-----
Temperature of steam	-----
Volume of inclosed air at zero	-----
Volume of inclosed air at boiling-point	-----
Amount of expansion of the air	-----
Expansion per degree	-----
Expansion per degree per unit of volume	-----
Accepted coefficient of expansion of air	-----
Error	-----
Percentage of error	-----

The volume of air is measured by the distance from the closed end of the tube to the inner end of the filament. As the tube is at 0°C . when packed in ice, the change in temperature will be equal to the temperature of the steam. Dividing the expansion by this change of temperature will give the expansion per degree, and dividing the expansion per degree by the volume at 0°C . gives the coefficient of expansion of air. It is the same for all gases.

EXERCISE XXXII

SPECIFIC HEAT OF A SOLID: COPPER

Apparatus. — A platform balance and a set of metric weights. A chemical thermometer. A basin of boiling water. A copper ball weighing 100 to 200 g., having a hook for attaching a cord. A copper cup or beaker of about 500 c.c. capacity for a **calorimeter**. A nickel-plated "lemonade shaker" makes an excellent calorimeter. For the method of calculation adopted in this exercise, the calorimeter and the ball must be of the same material.

Operations. — (1) Weigh the ball and place it in a basin of water that is kept boiling.

(2) Weigh the empty calorimeter.

(3) Fill the calorimeter about seven-eighths full of water, using sufficient to nearly fill the calorimeter when the ball is immersed in it. This water should be of about the same temperature as the air of the room, preferably one or two degrees colder. Weigh the calorimeter and water.

(4) Take the temperature of the boiling water containing the ball, exposing as much of the stem of the thermometer as possible to the water, or calculate it from the height of the barometer.

(5) Take the temperature of the water in the calorimeter *with great care*, estimating tenths of a degree. Avoid handling the calorimeter, and shield it from outside influences of heat or cold. Only a short interval of time should elapse between the taking of this temperature and the transferring of the ball to the calorimeter.

(6) Transfer the ball by the cord quickly to the calorimeter, being careful not to transfer any water with it. Move the ball up and down and to and fro, and *stir the water thoroughly* with the thermometer to equalize the temperature of the water, calorimeter, and ball.

(7) Take the temperature of the water and ball, *stirring the water with the thermometer*, and recording the highest temperature reached.

Tabulate as follows:—

Mass of the ball (<i>A</i>)	
Mass of the calorimeter (<i>B</i>)	
Mass of calorimeter plus water	
Mass of water taken (<i>C</i>)	
Temperature of water taken in calorimeter	
Temperature of ball in boiling water	
Temperature of water, calorimeter, and ball	
Change of temperature of water and calorimeter (<i>D</i>)	
Change of temperature of ball (<i>E</i>)	
Specific heat obtained for	
Accepted specific heat of	
Error	Percentage of error

Calculations.—Two principles are involved in the solution of this problem: First, that the amount of heat given off, or taken up, by a body equals *its mass* $\times$ *its specific heat* $\times$ *its change of temperature*. Second, that the amount of heat given off by the ball is transferred to and therefore equals that received by the water and calorimeter. Hence the two quantities can be equated:

Let x equal the specific heat of copper, that of water being 1. Then $A \cdot x \cdot E = C \cdot 1 \cdot D + B \cdot x \cdot D$.

The quantity $B \cdot x$ constitutes the **water equivalent** of the calorimeter; that is, it has the same capacity for heat as that number of grams of water.

Remarks. — The same method and apparatus may now be used for finding the specific heat of other metals, as lead or iron. The water equivalent of the calorimeter is added to the weight of water taken. Let F represent this sum, then the equation for solution of the problem becomes

$$A \cdot x \cdot E = F \cdot 1 \cdot D,$$

x being the specific heat of the substance.

EXERCISE XXXIII

LATENT HEAT OF MELTING

Apparatus. — A calorimeter. A thermometer. A platform balance. A large flat cork. Some clean ice.

Operations. — (1) Weigh the calorimeter.

(2) Prepare several lumps of clean ice about as large as a hen's egg.

(3) Pour into the calorimeter about 300 g. of water at a temperature of about 35° or 40° C. Ascertain the exact weight of the water and calorimeter.

(4) Place the calorimeter upon the cork; and, after stirring it well with the thermometer, take its temperature carefully. Its temperature should not be much above 40° C.

(5) Remove the thermometer, and as soon as possible introduce into the water 100 g. or more of ice. The ice should be clean and each lump should be wiped dry before being put in.

(6) As the resulting temperature when the ice is all melted will probably be about 10° , cool the thermometer to about 10° C. before beginning to stir the water and ice with it. This will remove the greater part of any error due to the heat of the thermometer.

(7) Stir the mixture gently with the thermometer until the ice is all melted, and immediately take its temperature.

(8) Weigh the calorimeter and the water it contains, to obtain the amount of ice that has been added.

If the water is not too warm at the beginning, it will not lose heat very rapidly by radiation during the experiment; and since the temperature during the latter part of the experiment will be below that of the room, the mixture will gain some in temperature, so that the error due to radiation will to a great extent be eliminated.

Tabulate the data as follows:—

Weight of calorimeter (<i>A</i>)	-----
Weight of calorimeter plus water	-----
Weight of water taken (<i>B</i>)	-----
Weight of calorimeter and water after ice is melted	-----
Weight of ice added (<i>C</i>)	-----
Temperature of water and calorimeter before addition of ice	-----
Temperature after ice is melted	-----
Number of degrees water and calorimeter were cooled (<i>D</i>)	-----
Number of degrees the ice after being melted was warmed (<i>E</i>)	-----
Latent heat of water found	-----
Accepted value	-----
Error	-----
Percentage of error	-----

Calculations.— Since the heat given out by the water and calorimeter in cooling was consumed by the ice in being melted and warmed after melted, the two quantities are equal and can be equated.

Let x = amount of heat required to melt 1 g. of ice without changing its temperature.

Let m = specific heat of copper, the substance of the calorimeter, found in a previous experiment. Then

$$C \cdot x + C \cdot 1 \cdot E = B \cdot 1 \cdot D + A \cdot m \cdot D.$$

Solve for x , the quantity required. This quantity is termed the latent heat of melting.

EXERCISE XXXIV

LATENT HEAT OF VAPORIZATION

Apparatus.—A calorimeter of about 500 c.c. capacity. A thermometer. A barometer. A Bunsen burner and a retort stand. A Florence flask fitted with a stopper and a

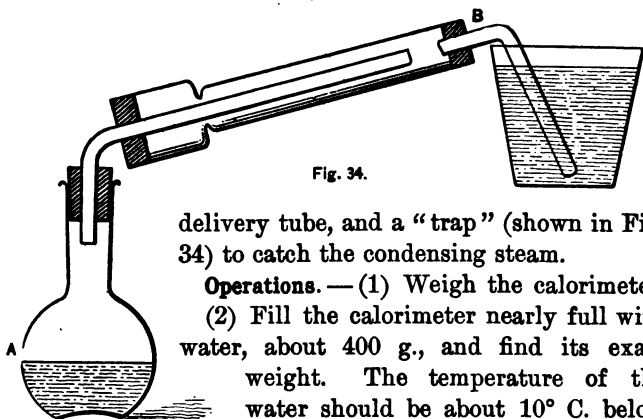


Fig. 34.

delivery tube, and a "trap" (shown in Fig. 34) to catch the condensing steam.

Operations.—(1) Weigh the calorimeter.

(2) Fill the calorimeter nearly full with water, about 400 g., and find its exact weight. The temperature of the water should be about 10° C. below that of the room.

(3) Take the temperature of the water, and then remove the thermometer.

(4) Immediately upon taking the temperature support the calorimeter so that the delivery tube B extends nearly

to the bottom of the water, first removing from the end of *B* any drops of water adhering to it. Have the water in the flask *A*, which should be about half full, boiling vigorously, so that a strong jet of steam issues from *B* when it is introduced into the water.

(5) Warm the thermometer, by holding it above the flame of the burner, to about 10° C. above the temperature of the room, and stir the water gently with it now and then.

(6) When the steam has raised the temperature of the water to about 10° above that of the room, or about 20° in all, remove it from the delivery tube and immediately take its temperature.

(7) Weigh the calorimeter and water again, to ascertain the amount of steam that has been added.

(8) Determine the temperature of the steam, either directly by a thermometer, as in Exercise XXIX., or by reading the barometer and computing the boiling-point, as in the same exercise.

By warming the thermometer, as directed in paragraph (5), to the same temperature to which the water is to be raised, no heat from the steam will be required to warm it; and by having the water at first about 10° below the temperature of the room and at the end about 10° above it, the gain and loss by radiation will be nearly equal. Thus the two chief sources of error will be largely eliminated.

Tabulate as follows:—

Weight of calorimeter (<i>A</i>)	-----
Weight of calorimeter plus water	-----
Weight of water taken (<i>B</i>)	-----
Weight of calorimeter plus water plus steam	-----
Weight of steam added (<i>C</i>)	-----
Temperature of water and calorimeter at beginning	-----
Temperature of water and calorimeter at end	-----
Barometer	-----
Computed or observed boiling-point	-----
Change of temperature of calorimeter and water (<i>D</i>)	-----

Change of temperature of steam after it is condensed to water (E) -----
 Latent heat of steam found. -----
 Accepted value -----
 Error ----- Percentage of error -----

Calculations. — Since the heat given out by the steam, first in condensing to water without change of temperature and then in cooling, was received by the water and calorimeter, the two quantities, that given and that received, must be equal, and can be equated.

Let x = heat given out by 1 g. of steam in condensing to water.

Let m = specific heat of substance of the calorimeter, as found in a previous exercise. Then

$$C \cdot x + C \cdot 1 \cdot E = B \cdot 1 \cdot D + A \cdot m \cdot D.$$

The value of x , when found, will be the latent heat of steam.

CHAPTER V

MAGNETISM AND ELECTRICITY



EXERCISE XXXV

FIRST LAW OF MAGNETS

Apparatus.—Two halves of a knitting needle, or two darning needles. A bar magnet. A cork. Some sealing wax. A saucer filled with water.

Operations.—(1) Magnetize the two needles by drawing the same pole of the bar magnet several times along the whole length of each, always in the same direction.

(2) Note which pole of the bar magnet is used and which end of the needle is last touched by it. Mark this end with sealing wax or in some other convenient way.

(3) Float one of the needles on a cork in the saucer of water. Mark the north-seeking pole in some convenient way. Repeat the operation with the other needle.

(4) Bring the north-seeking pole of the other needle near to the poles of the floating needle, and note the results. Try also the south-seeking pole. Then exchange the needles and repeat the operations.

Is the end of the needle last touched by the bar magnet the same in polarity as the pole of the bar magnet used, or opposite?

How do like poles affect each other? unlike poles?

EXERCISE XXXVI

EFFECT OF BREAKING A MAGNET

Apparatus.—A magnet. A compass or a floating needle such as that used in the last exercise. A piece of watchspring about 10 cm. long.

Operations.—(1) Magnetize the piece of watchspring and test and mark its poles.

(2) Break the spring into two pieces and test the ends of each piece for magnetism by the compass or the floating needle.

(3) Break these pieces and test the parts again as before. Continue this process of breaking and testing as long as you can.

(4) Lay the pieces down in their original order and note their arrangement as to their magnetic properties or poles.

Can you tell how this experiment supports two points of the theory of magnetism?

EXERCISE XXXVII

MAPPING A MAGNETIC FIELD

Apparatus.—A bar magnet. A large sheet of paper. A compass.

Operations.—(1) Place the magnet on the center of the sheet of paper with its north pole pointing north, and draw a line close to the magnet all about it, thus outlining the magnet upon the paper. Mark this outline with the letters N and S, corresponding to the poles of the magnet.

(2) Place the compass at the northeast corner of the

magnet and then move it slowly away, moving the compass in the direction in which the needle points, and changing the direction of motion as the needle changes its direction. Continue this movement until the edge of the paper is reached, or until the compass returns to the magnet.

(3) Trace upon the paper with a pencil the path taken by the center of the compass needle, indicating by arrow-heads the direction taken.

(4) In like manner trace several more lines of force, starting about a centimeter nearer the center of the magnet each time. Then in the same way map out the magnetic field on the west side of the magnet.

(5) Either fasten the paper in your note-book, or make a copy of the figure in the note-book.

EXERCISE XXXVIII

MAPPING A MAGNETIC FIELD BY IRON FILINGS

Apparatus. — Two bar magnets. A horseshoe magnet. A small piece of soft iron and an armature for the horseshoe magnet. A small muslin bag containing iron filings. A few pieces of thin boards.

Operations. —

PART A

(1) Place a bar magnet upon the table and about it some boards of the same thickness as the magnet, and then spread over these a smooth sheet of paper.

(2) Sift from the muslin bag iron filings evenly and thinly over this paper, and then tap it gently with a pencil or jar the table with the fist.

(3) Make a drawing in your note-book of the figure formed.

PART B

- (1) Place two bar magnets parallel to each other and about one-fourth their length apart, their unlike poles being adjacent. Map out the field in the same manner as in Part A.
- (2) Repeat the operation, having the like poles adjacent.

PART C: PERMEABILITY

(1) Map out as in the preceding exercise the magnetic field of a horseshoe magnet, first without any armature, then with an armature.

(2) Place the small piece of soft iron near, but not in contact with, the poles of the horseshoe magnet; or place it between the unlike poles of two bar magnets, but not in contact with them, and map out the field as before. The piece of iron should be about as large as a silver twenty-five cent piece, and as thick as the magnets. It can be kept from sliding towards the magnets by small bits of wood.

Permanent copies of these figures can be obtained by placing a sheet of unsized paper, moistened with a solution of tannin, carefully over the figure formed by the iron filings. Press the paper down gently upon the filings by a blotter and then lift it off carefully, allowing the filings to cling to the paper. When dry, brush off the filings and fasten the copies so made in your note-book.

EXERCISE XXXIX

THE SIMPLE VOLTAIC CELL

Apparatus. — (Fig. 35.) A tumbler about two-thirds full of dilute sulphuric acid, H_2SO_4 (1 part of acid to 15 or 20 parts of water). Two pieces of zinc and one piece of copper

about 10 cm. long and 3.5 cm. wide. The zincs, to be serviceable, should be 3 or 4 mm. thick. To each of these pieces of metal a piece of wood about $1 \times 1.5 \times 10$ cm. should be fastened by screws, and also a copper wire about 50 cm. long. One zinc should be well amalgamated, the other left unamalgamated.

A galvanoscope (Fig. 36), consisting of a small compass set in a block of wood about 10 cm. square and 5 cm. thick.

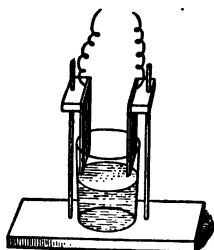


Fig. 35.

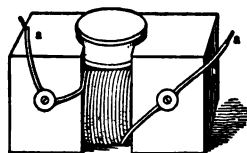


Fig. 36.

Extending under the compass and around the block is a groove in which are wound a few turns of insulated copper wire. Two connectors. A dinner plate upon which the metal strips may be placed when not in use.

Caution. — Do not allow the amalgamated zinc at any time to touch the other plates, as some of the mercury would be communicated to them.

Operations. — (1) Place each of the three plates in the acid separately, and observe what occurs at the surface of each.

(2) Place the copper and the unamalgamated zinc plates in the acid together, and observe what occurs at the surface of each; first, when they are not connected in any way; second, when touching under the liquid; and third, when connected by bringing the bare ends of the attached wires firmly together. This paragraph illustrates **local action**.

(3) Replace the unamalgamated by the amalgamated zinc and make the same observations as in the preceding paragraph, except that the two plates must not be allowed to touch under the liquid. Observe also the effect of intercepting the metallic connection between the plates by wood, cloth, paper, etc. Try also a bit of graphite taken from a lead pencil.

(4) Make the metallic connection through the wire of the galvanoscope, using the connectors; and observe the effect on the needle when the metallic connection is complete and when it is intercepted by wood, cloth, paper, etc.

Before using the galvanoscope, place it so that the groove in the block lies in the magnetic meridian and keep it in that position while using it.

(5) Compare the effect produced on the needle when the unamalgamated zinc is used, with that produced by the use of the amalgamated zinc.

(6) Again, with the amalgamated zinc, observe the effect on the needle of brushing off the bubbles from the plate with a small swab after the current has been flowing about five minutes.

(7) Place the two zincs in the acid and connect them to the galvanoscope. Observe whether there is any effect on the needle or not. If there is, determine which one has taken the place of the copper plate. Try also two amalgamated zincs or two unamalgamated zincs.

(8) Observe whether any of the plates have been wasted away by the action of the acid.

(9) Place a copper and a zinc plate in a solution of common salt in water, and note the effect on the needle of the galvanoscope.

Examine different kinds of cells, and read about them, noting the fluid used for the *exciting* action and the material used for the *depolarizing* action. (See Thompson, pp. 157-174, new ed., pp. 131-145, old ed.)

EXERCISE XL

ELECTROMAGNETS

Apparatus.—Some form of a voltaic cell, such as a Leclanché, a gravity, or the simple cell used in the last exercise. A bar of soft iron about 15 cm. long and 1 cm. in diameter, with a file-mark near one end. Two or three meters of insulated copper wire about No. 22. A compass. Some iron filings.

Operations.—(1) Test the bar for residual magnetism, both by the compass and by iron filings.

(2) Wind the wire about the bar in a neat close spiral, connect the free ends of the wire to the battery, and again test the bar as before. Break the circuit and again test the bar.

(3) While the current is flowing, determine and mark the north pole of the bar or *core*. Then, without unwinding the wire, change the direction of the current in the wire by changing the connections with the cell and determine again the north pole of the core.

(4) Determine the effect on the polarity of the core when the direction of the current in the wire itself is not changed, but the direction about the core is changed by unwinding the wire and rewinding it in the opposite direction.

(5) Grasp the rod in the right hand in such a way that the fingers shall encircle it in the same direction as that in which the current flows. Note toward which pole the thumb points, and thus devise a rule by which the poles of an electromagnet can be determined, when the direction of the current is known; or the direction of the current, when the poles are known.

(6) Note the effect of a smaller number of spirals about the core upon the strength of its magnetism.

The student should now examine and study an electric bell, telegraph sounder, and other instruments of which an electromagnet forms a part.

EXERCISE XLI

DEFLECTION

Apparatus. — A voltaic cell. About 1 m. of insulated copper wire No. 22, attached to one pole of the cell. A compass or magnetic needle.

Operations. — (1) Place some portion of the wire parallel to and above the needle, so that the current which flows through the wire toward the zinc plate of the cell shall flow from north to south above the needle. Note the effect on the north pole of the needle upon closing the circuit by bringing the free end of the wire in contact with the other plate of the cell.

(2) Try the same with the current flowing from south to north above the needle.

(3) Note the effect when the wire is placed under the needle so that the current flows from north to south below the needle.

(4) Again note the effect with the current flowing from south to north below the needle.

(5) Place a portion of the wire in a vertical position near the north pole of the needle and note the effect, first, when the current is flowing up, and then when the current is flowing down. To do this easily, support the compass on a small block or other object.

(6) Repeat the last operations at the south pole of the

needle. Can you tell from the results of the above operations what the effect would be if the current were passed entirely around the needle in a north and south vertical plane?

(7) Pass the wire once around the needle in a north and south vertical plane, and note the effect when the current is flowing first in one direction and then in the other. Also note the effect of an increased number of turns of wire upon the deflection of the needle.

It is interesting to note whether the distance of the wire from the needle, or the interposition of such substances as wood, glass, etc., between the wire and the needle, affects the deflection.

(8) Put the right hand in place of the wire in each of the above cases, with the palm toward the needle and with the fingers pointing in the direction in which the current was flowing. Compare in each case the direction in which the thumb points with the direction in which the north pole of the needle is turned. From this, if possible, derive a rule for determining the deflection when the direction of the current is known, or the direction of the current when the deflection is known.

Remarks. — It is evident that if the needle or magnet were fixed in its position and the coil arranged so as to turn easily, the coil would be turned so as to assume an angle with the magnet when the current is sent through it. Galvanometers consist essentially of a coil of wire and a magnet. In some instruments the magnet is the movable part and the coil is stationary, while in others the reverse is true. It would be well for the student now to make a study of galvanometers both by reading about them and by examining any available instruments.

EXERCISE XLII

AN ELECTROMOTIVE SERIES

Apparatus. — Same as for Exercise XXXIX., and in addition plates of iron, lead, carbon, and aluminum.

Operations. — (1) Taking one of these plates, as copper, form a cell with each of the others in turn, and by the galvanoscope determine in each case which is the positive and which is the negative plate.

(2) Continue the above process until as many different combinations as possible have been made with the five plates.

(3) Arrange the plates in a series such that if any two of them be taken to form a cell, the first in the series shall be the positive plate.

Record the data in a table as follows: —

No.	Positive Plate.	Negative Plate.	Series.
1			
2			
3			
etc.			
$\frac{1}{2}$	1	1	1

THE TANGENT GALVANOMETER

[See the Appendix for instructions for making a galvanometer.]

The law of the tangent galvanometer is that the *strength of the current is proportional to the tangent of the angle of deflection*. For example, suppose that a current of 0.8 of

an ampere, passed through a tangent galvanometer, produces a deflection of 31° , and that another current of unknown strength produces a deflection of 52° . By the above law the strength of the second current can be determined

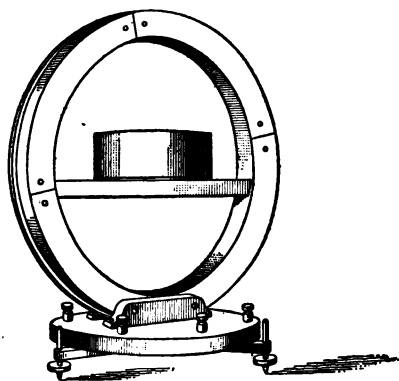


Fig. 37.

by comparing it with the first. (See S. P. Thompson's *Elementary Lessons in Elec. and Mag.*, pp. 163-165, old ed., 198-200, new ed.).

Let x = equal the strength of the unknown current.

Then

$$0.8 : x :: \tan 31^\circ : \tan 52^\circ.$$

From a table of tangents (Appendix, Table XVII., pp. 182, 183), it is found that $\tan 31^\circ$ is 0.6 and $\tan 52^\circ$ is 1.28; hence

$$0.8 : x :: 0.6 : 1.28,$$

$$x = 1.7 \text{ amperes.}$$

It is evident from the above illustration that it is necessary to know what deflection some known current will produce in any particular galvanometer in order to use the galvanometer for measuring strength of currents.

It is most convenient and therefore customary to take for the known current that current strength which will cause a deflection of 45° . This is most convenient merely because the tangent of 45° is 1. This current that causes a deflection of 45° is called the **reduction factor** or **galvanometer constant**.

Each galvanometer, or, if it has more than one coil, each coil of a galvanometer, has its own reduction factor, which must be determined before the galvanometer can be used for measuring the strength of currents. The value of the reduction factor depends upon the number of turns of wire in the coil, the radius of the coil, and the strength of the earth's magnetic field where the galvanometer is set up.

To illustrate the use of the reduction factor, when once it is determined, let k = the reduction factor, and A° the deflection produced by a current of unknown strength represented by x . Then

$$k : x :: \tan 45^\circ : \tan A^\circ,$$

$$k : x :: 1 : \tan A^\circ,$$

$$x = k \times \tan A^\circ.$$

REMARKS ON THE USE OF THE TANGENT GALVANOMETER

The instrument should be placed on a firm table where it will be as free as possible from disturbance and local iron influences, and where, if possible, it can remain undisturbed for an indefinite time. In placing the instrument, see that it is level, that the plane of the coil is in the magnetic meridian, and that the two ends of the pointer are at zero. When once adjusted in position, great care should be taken not to move it from its position.

Because of imperfect adjustment of the galvanometer, the needle, and its pointer, it often happens that the read-

ings at the two ends of the pointer are not the same and do not agree with those given when the current is reversed. These errors, which should be small, may be caused by the pointer not being straight and at right angles to the needle, or by the axis on which the needle turns not being at the center of the graduated circle, or by the pointer not being adjusted to zero at both ends at first. To eliminate these errors, it is necessary to take double readings; that is, to read the position of each end of the pointer and then reverse the current and take the readings again. The average of the four readings taken must be considered as the true deflection.

The observer must be careful not to have any iron about his person. If a movement of the needle occurs upon the approach or the retirement of the observer from the instrument, it is an indication that there is some iron or steel, such as knives, keys, or stays, about the clothing of the observer that will render accurate work impossible.

Parallax must be avoided by placing the eye above the needle so that the pointer hides its own image in the mirror beneath.

Whenever possible, it is best to arrange the apparatus or to select the coil of the galvanometer so that the deflection shall not vary widely from 45° , since the effect of an error in reading is less at that point than at any other. An error of 1° at 45° will produce an error of about 3.5 per cent in the result; while an error of the same amount at 10° , or 80° , will produce an error in the result of about 10 per cent. (See S. & G., Vol. II., pp. 229-232.)

To prevent the connecting wires from influencing the needle of the galvanometer, they should be twisted together where they approach the instrument.

For the explanation of the meaning of *tangent* of an *angle*, see p. 152.

EXERCISE XLIII

REDUCTION FACTOR OF A TANGENT GALVANOMETER

BY A GAS VOLTAMETER

Apparatus.—A tangent galvanometer. A commutator (Fig. 38). A rheochord. A voltameter. A watch. A battery of from four to six Daniell cells. An inverted burette

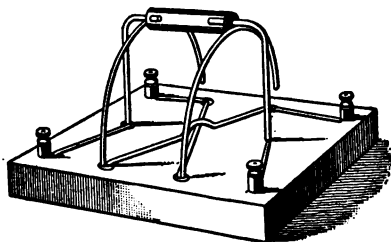


Fig. 38.

makes an excellent voltameter. It is easily filled by suction through a rubber tube attached to the lower end, after it is inverted (Fig. 39).

Operations.—(1) Fill the voltameter with water containing from 20 to 30 per cent of sulphuric acid. (A 30 per cent solution has the greatest conductivity. See S. & G., Vol. II., p. 251.)

(2) Connect the apparatus as shown by Fig. 40, in which *G* represents the galvanometer, *C* the commutator, *R* the rheochord, *V* the voltameter, and *B* the battery. Use that coil of the galvanometer that will give a deflection between 30° and 60° . Before beginning final operations, close the circuit in order to see that the apparatus is in good working condition and that there is a suitable deflection of the

needle, about half of the rheochord resistance being in use. Then break the circuit at the commutator.

(3) Note and record the volume of gas in that tube of the voltameter that is over the negative electrode, or *cathode*. This tube should not be quite full of water.

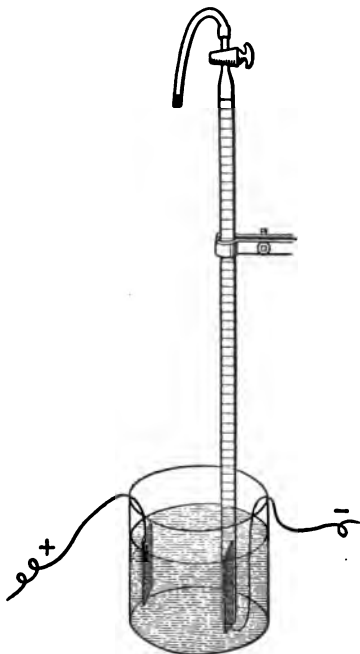


Fig. 39.

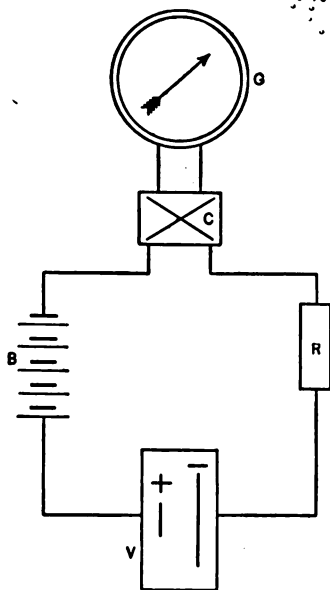


Fig. 40.

(4) Close the circuit at the commutator, observing and recording the exact time at which it is done.

(5) Observe the deflection of the needle at each end, and then reverse the current by the commutator and read the deflection again. Allow the current to flow for about fifteen

minutes, or until 30 or 40 c.c. of hydrogen have been generated. Observe the needle carefully during this time, and keep the deflection and current constant by varying the resistance of the circuit by the rheochord. If a Daniell battery is used, it is probable that the resistance of the circuit will not need to be changed during the experiment.

(6) Break the circuit at the commutator, noting the exact time at which it is done.

(7) Observe the volume of gas in the voltameter.

NOTE.—For a more accurate determination of the constant, the volume of hydrogen should be corrected for temperature and pressure. A weight voltameter, however, is to be preferred for more accurate work.

Record the data as follows:—

Volume of gas in voltameter at first.....
 Volume of gas in voltameter at end.....
 Volume of gas generated.....
 Time of closing the circuit.....
 Time of breaking the circuit.....
 Time the current flowed, in seconds.....
 Deflections.....
 Average deflection.....
 Reduction factor.....

Calculations.—Dividing the amount of hydrogen generated by the number of seconds the current flows gives the volume of hydrogen generated per second; and dividing the quotient thus obtained by 0.1155 gives the strength of the current in amperes flowing through the whole circuit, since one ampere flowing for one second (that is, one coulomb) liberates 0.1155 c.c. of hydrogen at 0° C. and 76 cm. pressure. (See Thompson, art. 243, revised ed., art. 215, old ed.)

Let B = the strength of current found.

Let A = the average deflection.

Then, by the law of the tangent galvanometer,

$$B : x :: \tan A : \tan 45,$$

$$B : x :: \tan A : 1,$$

$$x = \frac{B}{\tan A},$$

which equals the current that will deflect the needle 45° , or the reduction factor of the galvanometer coil used.

EXERCISE XLIV

REDUCTION FACTOR OF A TANGENT GALVANOMETER

A. BY A COPPER VOLTAMETER

Apparatus.—Same as for Exercise XLIII. except that the voltameter (Fig. 41) consists of two copper electrodes in a solution of copper sulphate, CuSO_4 , which contains 30 g. of the salt to every 100 g. of water and 1 per cent of free sulphuric acid, or a solution of about 1.17 density.

To make the electrodes, take a piece of No. 14 copper wire about 2 m. long for each electrode, and clean it thoroughly by fastening one end in a vise and rubbing it with sandpaper. Be careful not to touch the wire with the fingers after it is cleaned. Wind the wires into neat spirals, making one about 4 cm. and the other about 8 cm. in diameter. The area of these electrodes should not be less than 50 sq. cm. each for one ampere of current used. They are to be placed vertically in the solution, the smaller,

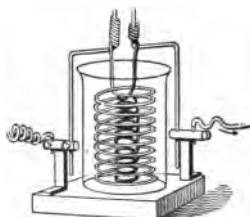


Fig. 41. — Weight Voltameter.

or cathode, being placed concentrically within the other (see Fig. 41).

Operations.—(1) The anode is ready for use without further cleaning. Clean the cathode by dipping it first in water containing a little sulphuric acid, then dry it by blotting paper, and then dip it in strong alcohol. Dry again first by clean blotting paper, and then by a current of warm air. The part to be immersed in the solution must not be touched with the fingers after it is polished with the sand-paper.

(2) Weigh the cathode, or gain plate, by a Jolly balance or a chemical balance.

(3) Place the electrodes in position, make the connections, take the time, deflections, etc., as in Exercise XLIII. The current should flow from one to three hours, being kept constant by means of the rheochord.

(4) Clean and weigh the cathode again as before.

Calculations.—The calculations are the same as in Exercise XLII., except that the weight of the cathode is taken instead of the volume of the gas liberated at the cathode. The weight of copper deposited per second is divided by 0.000328, the number of grams deposited in one second by one ampere, to obtain the strength of the current.

NOTE.—Before washing and weighing the cathode for the first time, it is well to set up the apparatus and test it to see that it is in good working order.

B. BY A SILVER VOLTAMETER

A silver voltameter is to be preferred to one of copper, because it is more accurate and because the weight of the silver deposited on the gain plate is more than three times that of copper by the same current. The experiment can therefore be made in much shorter time by the silver voltameter, or with weaker currents. The cost is not great.

The apparatus and the method are, in general, the same as for the copper voltameter.

The electrodes should be of pure silver, 2 or 3 mm. thick and having an area of not less than 200 sq. cm. for one ampere of current. Each may be in a form of a square plate, having a tongue projecting from one side by which it can be handled and supported.

To clean the plates, dip them for a moment in weak nitric acid and then wash them thoroughly in distilled water. The cathode, or gain plate, should then be washed in alcohol, dried in warm air, and, when cool, carefully weighed.

On removing the cathode from the solution after the deposit has been made, wash it very thoroughly in distilled water, then in alcohol, and then dry and weigh as before. The plate must be handled with great care, as the silver does not adhere very strongly and may be removed by careless handling and washing, thus vitiating the results.

The solution should contain 15 g. of silver nitrate to 85 g. of water.

The weight of silver deposited per second is divided by 0.001119, the number of grams deposited in one second by a current strength of one ampere.

Remarks. — Since the manipulations in the last two exercises are rather difficult, it is recommended that the teacher perform the experiments in conjunction with the whole laboratory section. After one galvanometer has been standardized, it can be used for standardizing other galvanometers, or several galvanometers can be connected in series and all standardized at the same time.

To determine the reduction factor of a galvanometer by means of another whose constant is known constitutes an excellent laboratory exercise. The two galvanometers, battery, and resistance box should be connected in series, the commutator being next to the battery. Place the galva-

nometers several feet apart, so that they will not influence each other. The galvanometer whose constant is known serves the same purpose as the voltameter in Exercises XLIII. and XLIV.

If one is so fortunate as to possess a commercial ammeter, it can be used for standardizing the galvanometer, and it can be advantageously substituted for the tangent galvanometer wherever that is used in the following exercises.

EXERCISE XLV

A POLARIZATION CURVE

Apparatus.—A Leclanché cell. A resistance box. A tangent galvanometer. A watch.

Operations.—(1) Connect the cell, the resistance box, and all of the coils of the galvanometer in series, making the resistance of the box about 10 ohms.

(2) As soon as the needle comes to rest, observe the deflection, and every half minute thereafter for the first five minutes. During the next five minutes record the position of the needle every minute, and after that every two minutes for the next twenty minutes.

(3) Find the tangent for each deflection.

(4) Using the times for the abscissas and the tangents as ordinates, plot a curve showing the relation between the current, diminished by polarization, and the time.

Record the data as follows:—

Time.	Deflections.	Tangents.
$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$

EXERCISE XLVI

JOINING CELLS

Apparatus.—Three or four Daniell cells. A tangent galvanometer with a long, high resistance coil and a short, low resistance coil. (Use all of the coils of the galvanometer joined in series for the high resistance, and the two short, thick wire coils for the low resistance, the constants in both cases being given.) A resistance box or a spool of German silver wire of about 100 ohms' resistance. A commutator. Some connectors and short, thick pieces of wire.

Operations.—(1) Using one cell only, join it to the low resistance galvanometer and determine the average deflection.

(2) Using one cell as before, introduce into the circuit about 100 ohms' resistance and join to the high resistance galvanometer. Determine the average deflection as before.

(3) Join all the cells *parallel*, that is, connect all the negative plates together and all the positive together, and then connect the battery to the low resistance galvanometer. Ask the instructor to examine the connections, and then determine the deflection as before.

(4) With the cells still joined parallel, introduce 100 ohms into the circuit and join to the high resistance galvanometer, determining the deflection again.

(5) Join the cells in series; that is, connect the positive plate of one cell to the negative plate of the next cell, and so on until all the cells are joined, the negative of the first cell and the positive plate of the last cell forming the poles of the battery. Let the instructor again examine the connections. Connect the battery to the low resistance galvanometer and determine the deflection.

(6) With the cells still in series, introduce into the circuit

100 ohms and join to the high resistance galvanometer. Determine the deflection.

Observe that in the cases in which additional resistance is introduced into the circuit, the high resistance or long coil galvanometer is to be used; and that in the other cases, in which the external resistance is made as small as possible, the low resistance or short coil galvanometer is to be used.

Record the data as follows:—

GALVANOMETER-----									
Coil Used.	No. of Cells.	How Joined.	R. of Box.	Deflections.		Ave. Def.	Tangents.	K. of Gal.	Currents.
				Dir.	Rev.				
$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$

Compare the results obtained in the first, third, and fifth cases with one another; and likewise, those of the second, fourth, and sixth cases.

EXERCISE XLVII

OHM'S LAW

Apparatus.—The slide-wire Wheatstone bridge, used in Exercise XLVIII., which in this exercise is not used as a bridge (see Appendix, p. 161). A small block of wood 7 or 8 cm. square and 2 or 3 cm. thick, having a piece of sheet brass fastened to one side and projecting about 1 cm. beyond the corner of the block. About 1 m. of wire should be soldered to this piece of brass. This block (*D*, Fig. 42) is to be used to



Fig. 42.

make the connection with the bridge wire at *B* (Fig. 43), by resting the edge of the brass strip on the wire, a weight being placed on the block to hold it in position. A battery of a few Daniell cells. A commutator. A D'Arsonval galvanometer (see Appendix, p. 161) with

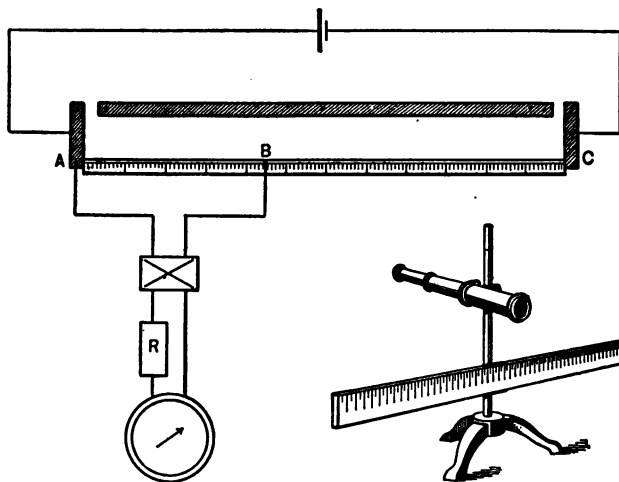


Fig. 43.

Fig. 44.

telescope and scale (Fig. 44). A high resistance of about 5000 ohms, consisting of a spool of wire or pencil lines upon ground glass.

Operations. — (1) Connect the apparatus as shown in Fig. 43.

(2) Make the connection at *B* 10 cm. from *A*, and determine the average deflection; and then repeat the operation, placing *B* at intervals of 10 cm. along the wire until *C* is reached.

Record the data as follows: —

Deflection.			Length AB .	Length AB .
First.	Second.	Average.		Deflection.

Using the values of AB and the corresponding deflections as co-ordinates, plot a curve showing graphically the relation between them.

With the telescope and scale arrangement the current is proportional to the deflection. What relation, therefore, exists between the *current* through the galvanometer and the *length* AB ? Between the *length* AB and the *resistance* from A to B ? What then is the relation between the *current* through the galvanometer and the *resistance* from A to B ?

The current through the galvanometer is due to the difference of potential between A and B , and is proportional to it. What must be the relation, therefore, between the *difference of potential* from A to B , and the *resistance* from A to B ? Difference of potential here is equivalent to electromotive force, hence what is the relation between *electromotive force* and *resistance*?

The student must note that two currents are considered in this exercise,—the current through the galvanometer, which is variable, and the current through the wire ABC , which must be constant. The resistance of the galvanometer circuit being large, only a minute fraction of the main current through the wire ABC flows through the galvanometer, hence the constancy of the current is practically unaffected by making and breaking the connection at B . Ohm's law implies that E is proportional to R when C is constant. In this exercise C is constant; have you shown that E is proportional to R ?

NOTE.—Should a tangent galvanometer be used, place another column in the table for the tangents of the angles of deflection and in the last column place the quotients of the tangents divided by lengths AB .

A voltmeter may be substituted for the galvanometer and resistance, and then the quotients of the readings of the instrument by the lengths AB should be placed in the last column.

EXERCISE XLVIII

RESISTANCE OF WIRES BY WHEATSTONE SLIDING
BRIDGE

Apparatus. — A D'Arsonval galvanometer with telescope and scale. A Leclanché cell. A resistance box or some standard resistance coils. A Wheatstone sliding bridge (see Appendix, p. 161). Some spools of copper and German silver wire of known lengths and various diameters. A micrometer screw.

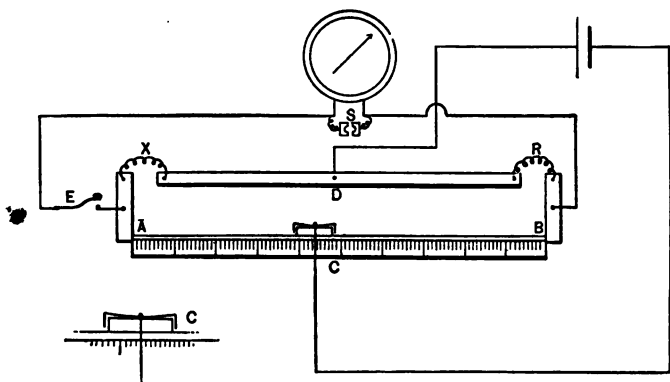


Fig. 45.

Operations. — (1) Connect the apparatus as shown in Fig. 45, in which X represents the unknown resistance, R the known resistance, E the galvanometer key, and C the battery key. Place the telescope and scale so that the scale reflected in the mirror of the galvanometer can be read through the telescope, the galvanometer being about 2 m. distant.

(2) The process of measuring the resistance of X consists in finding such a position for C on the wire AB that when

the key E and the battery key C are both closed, no current shall flow through the galvanometer. This is done by trial as follows:—

First, find two places for C that cause opposite deflections of the galvanometer. The place sought must be between these two points.

Second, note the direction of the deflection when C is too far to the right or too far to the left, so that the direction of the deflection will thereafter enable you to tell which way to move C .

Then continue to move C about until the correct position for it is found. When it is found, check the result by making contacts 1 mm. on either side of it. These contacts should cause about equal deflections in opposite directions.

During the first trials it is well to shunt the galvanometer at S and to close the key E for an instant only, to avoid injury to the galvanometer by too violent deflections. When the correct place for C is approximately found, the shunt S should be broken and longer contacts at E will be necessary.

To bring the galvanometer to rest quickly between each trial, hold down the key E , the key C being open. The key E at each trial should always be closed and opened while the key C is closed; that is, *close the battery key first and open it last*.

It is desirable, although not necessary, that the correct point for C should be near the middle of the bridge wire. This will occur when the known resistance R and the unknown resistance X are of about the same value.

(3) Measure the diameter of the wire whose resistance is being determined with the micrometer screw or its diameter may be taken from a table, if its number is known.

Record the data as follows:—

Kind of Wire.	No. of Wire.	Diameter.	Square of Diameter.	Length of Wire.	R.	Length AC.	Length BC.	X.	K.
$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$

Compare the resistances of wires of the same material and diameter with their lengths; then, of the same material and length with their diameters and the squares of their diameters. Calculate in each case from the data obtained the resistance of 1 ft. of wire, $\frac{1}{1000}$ of an inch in diameter, represented by K in the table.

Theory of the Bridge. — Let a = the fall of potential from D to A , b the fall from D to B , and c the fall from D to C . The fall of potential from D to C will of course be the same by either path, DAC or DBC . Let R' = the resistance of AC and R'' the resistance of BC . Then, since the fall of potential along a conductor is proportional to the resistance (Exercise XLVII.), we have the two proportions,

$$\frac{a}{c} = \frac{X}{X + R'} \text{ and } \frac{b}{c} = \frac{R}{R + R''}.$$

But when there is no current through the galvanometer, A and B are at the same potential and $a = b$; hence

$$\frac{X}{X + R'} = \frac{R}{R + R''}. \text{ This simplified gives the proportion}$$

$$\frac{X}{R} = \frac{R'}{R''}. \text{ But since resistance is proportional to the length}$$

of a conductor, $\frac{R'}{R''} = \frac{\text{Length } AC}{\text{Length } BC}$; hence

$$\frac{X}{R} = \frac{\text{Length } AC}{\text{Length } BC},$$

a proportion by which the value for X in the table can be determined.

EXERCISE XLIX

MEASUREMENT OF ELECTROMOTIVE FORCE

References.—S. & G., Vol. II., pp. 221–224, 484, 485; G. & S., pp. 567–571; Fleming, pp. 128–135.

Apparatus.—A rheochord consisting of 6 m. of No. 28 German silver wire. A sensitive galvanometer, a D'Arsonval is best. A resistance box. Three or four Daniell cells and a cell whose electromotive force is to be determined. A movable contact key such as that used in Exercise XLVIII.

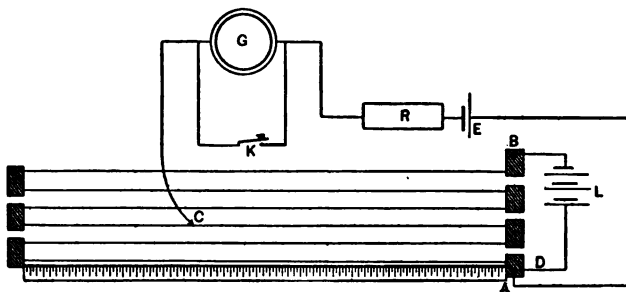


Fig. 46.

Operations.—(1) Connect the apparatus as shown in Fig. 46, in which *E* is a single Daniell cell used as a standard of E.M.F. The battery at *L* must be of such strength and its internal resistance so proportioned to that of the wire of the rheochord that the fall of potential from *A* to *B* will be greater than the E.M.F. of any cell or battery to be placed at *E*. For testing cells no stronger than a Leclanché cell, two Daniell cells at *L* are sufficient. The same poles of the cell at *E* and of the battery at *L* must be connected to *A*. Make the resistance at *R* 100, or more, ohms, or as large as the sensitiveness of the galvanometer will permit.

(2) As in Exercise XLVIII., find a position for the sliding key *C*, on the wire of the rheochord, such that when it is closed there shall be no deflection of the galvanometer. Until the correct position for *C* is nearly attained, the key at *K* should be kept closed, to act as a shunt for the galvanometer. This key should also be closed between all trials, to bring the galvanometer to rest. The resistance at *R* should be as large as possible and yet have the galvanometer sensitive to a slight change of the position of *C*.

(3) Substitute for the Daniell cell that whose E.M.F. is to be measured, and again find a position for the sliding key *C*, on the wire of the rheochord that will cause no deflection of the galvanometer.

By placing two cells joined parallel, or in series, at *E*, their E.M.F. can be compared with that of one cell of the same kind.

The E.M.F.'s of the cells at *E* will be directly proportional to the length of the wire between *A* and *C*. For the E.M.F. of the Daniell cell use 1.1 volts.

Explanation. — The galvanometer circuit from *A* to *C* forms a shunt circuit in that of the battery at *L*, and the cell at *E* tends to set up a current in opposition to that from *L*. When *C* is closed at the right place on the wire, so that there is no current in the galvanometer circuit, it is the same as if it were not closed, because no current flows; and the E.M.F. of the cell at *E* will just equal the difference of potential between *A* and *C*. In Exercise XLVII. it was shown that the difference of potential between *A* and *C* is proportional to the length of the wire between *A* and *C*. Hence the E.M.F. of the cells at *E* will be proportional to the lengths of the wire from *A* to *C*. This holds true as long as the resistance of the circuit of *L* remains the same and the strength of the current from *L* is constant.

Record the data as follows:—

Cells at <i>L</i> .	Cell at <i>E</i> .	Length, <i>A</i> to <i>C</i> .	E.M.F.
1	1	1	1

EXERCISE L

RESISTANCE OF A CELL

MANCE'S METHOD

Apparatus.—A Wheatstone sliding bridge. A gravity or a Daniell cell. A resistance box. A D'Arsonval galvanometer with telescope and scale, or a tangent galvanometer.

Operations.—(1) Referring to Fig. 45, substitute the cell whose resistance is to be measured for *X*, and remove the battery from the line *CD*, leaving *CD* connected by a wire. The key *E* may be closed permanently, or removed from the galvanometer circuit. The galvanometer will be deflected. If the deflection is much more than 45° with a tangent galvanometer, or off the scale with a D'Arsonval, it should be reduced by a shunt.

(2) Find by trial, as in the preceding experiment, a point *C* on the bridge wire, such that when the key is closed at *C* no change occurs in the deflection of the galvanometer. The points *C* and *D* are then at the same potential, and *X*, the resistance of the cell, is to *R* as the length *AC* is to the length *BC*, $\frac{X}{R} = \frac{AC}{BC}$. Make *R* as nearly as possible equal to *X*. Find the average of three different determinations.

Record the data as follows : —

<i>R.</i>	<i>AC.</i>	<i>BC.</i>	<i>X.</i>
$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$

EXERCISE LI

RESISTANCE AND E.M.F. OF A CELL

Apparatus. — A tangent galvanometer whose constant and resistance are known. A commutator. A resistance box. A Daniell or a gravity cell.

Operations. — (1) Connect the instruments in series, using all the coils of the galvanometer, and draw a diagram of the instruments and the connections in the note-book.

(2) Make the resistance (R') of the resistance box such that the deflection shall be nearly 60° , and determine the average deflection.

(3) Change the resistance of the box so that the deflection shall be about 30° , designating the resistance in this case by R'' . Determine the average deflection.

Explanation. — Ohm's law, $C = \frac{E}{R}$, indicates that C is inversely proportional to R when E is constant. In this experiment the R of the circuit is the sum of the resistances of the galvanometer, the box, and the cell. Let g = the resistance of the galvanometer, and r that of the cell, R' being that of the box in the first case, and R'' in the second case. Then in the first case the resistance of the circuit was $R' + g + r$, and in the second case $R'' + g + r$. Let C and C' represent the currents in the two cases. Then

$$C : C' :: \frac{E}{R' + g + r} : \frac{E}{R'' + g + r}$$

But since the currents are proportional to the tangents of the angles of deflection, the tangents can be substituted for the currents in the above proportion.

Let A = the average deflection in the first case.

Let A' = the average deflection in the second case.

Then

$$\tan A : \tan A' :: \frac{1}{R' + g + r} : \frac{1}{R'' + g + r},$$

from which the value of r can be determined. This proportion may be simplified, and reduced to the following equation,

$$r = \frac{T_1 R_1 - T_2 R_2}{T_2 - T_1},$$

in which $T_1 = \tan A$, $T_2 = \tan A'$, R_1 the resistance $R' + g$, and R_2 the resistance $R'' + g$. When r is known, the E.M.F. of the cell may be calculated by Ohm's law.

Record the data as follows:—

GALVANOMETER -----				COILS USED -----			
Galvanometer Constant -----				Galvanometer Resistance -----			
Kind of Cell.	Box Resistance.	Deflections.		Average Deflection.	Tangents.	Currents.	E.M.F.
		Direct.	Reverse.				
$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$

CHAPTER VI

SOUND

EXERCISE LII

SCALE RATIOS

Apparatus.—A siren consisting of a disk of brass or cardboard with eight concentric circles of holes, mounted on an electric motor or on a whirling table. A bellows fitted with a rubber tube, into the end of which a glass tube is inserted.

Operations.—(1) Count the number of holes in each circle, beginning with the inner circle.

(2) Express the number of vibrations that each circle will produce when the disk is rotating and a jet of air is directed at each circle in succession. To do this, let n denote the number of rotations per second made by the disk. Each puff of air as it passes through a hole may be considered a vibration; and, therefore, there will be as many vibrations per second for any circle as there are holes in the circle multiplied by n , *e.g.* if there are 24 holes in the first circle, $24n$ will express the number of vibrations per second for that circle.

(3) Express the ratio of the number of vibrations per second produced by each circle to the number produced by the inner circle. Since n is a common factor in each of

these, it will cancel out; and hence n , or the rate of rotation, does not need to be known.

(4) Set the disk in rotation; and when it has attained a uniform speed, direct a jet of air against each circle of holes in rapid succession, beginning with the inner circle. Be careful that the tube does not touch the disk. Designate

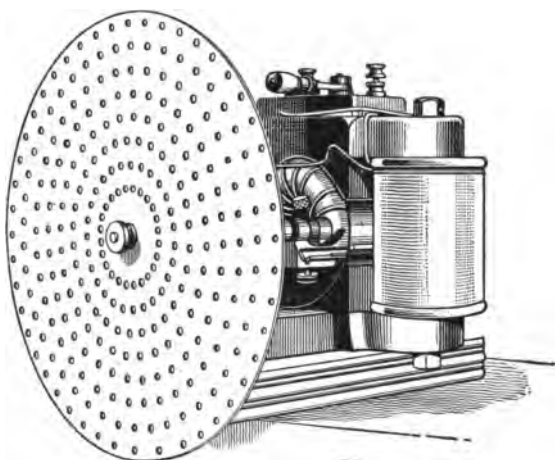


Fig. 47.

the tones produced by the customary names. (Instead of using a bellows to produce the jet of air, place the rubber tube in the mouth and blow air from the lungs through the holes of the disk.)

What vibration ratio corresponds with each tone produced?

(5) Set the disk in rotation and direct a jet of air at a single circle of holes while the rate of rotation is increasing. What relation between vibration rate and pitch does this illustrate?

Record the data as follows:—

Circle.	1	2	3	4	5	6	7	8
Number of holes	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Number of vibrations								
Ratio of vibrations								
Tones *								

EXERCISE LIII

VIBRATIONS OF STRINGS: LAW OF LENGTH

Apparatus. — A sonometer (Fig. 48) fitted with a single string and having three bridges.

Operations. — (1) Place the two bridges under the wire at some known distance apart, as 80 or 100 cm. Pluck the



Fig. 48.

wire with the finger and use the tone produced as the key-note, or *Do*, in the following operations.

(2) Place the third or movable bridge under the wire between the two bridges at such a point that the wire will give the note *Re*. This position is to be found by trial by the aid of the ear. The whole wire should be sounded frequently to aid the ear in finding the correct point. Measure the length of the wire giving the note *Re*.

* Designate the tones produced by the customary names.

(3) In like manner determine the lengths for the remaining notes of the scale.

(4) Repeat the operation several times with the same length of wire for the *keynote*, measuring this length now and then to see that the bridges are not out of place. Find the average of the lengths found for each of the notes of the scale. The average of a large number of somewhat rapid determinations is to be preferred to a few determinations taken very slowly. Be careful not to increase the tension of the wire by lifting it with the movable bridge.

(5) Find the ratio of each of the average lengths for the notes of the scale to the length of the wire for the keynote, expressing the ratios decimally.

(6) Express decimally the reciprocals of the scale ratios found in the last exercise, and compare them with the ratios just found.

Record the data as follows:—

NOTES.	Do.	Re.	Mi.	Fa.	Sol.	La.	Si.	Do.
Lengths of wire, 1st trial	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
2nd trial								
3rd trial								
etc.								
Average of lengths								
Ratio of average lengths to length of keynote								
Reciprocals of scale ratios								
Error in each case								
Percentage of error								

EXERCISE LIV

VIBRATION OF STRINGS: LAW OF DIAMETER

Apparatus.—A sonometer fitted with two strings of piano wire of different diameters. These wires (C and D , Fig. 49) at one end are fastened to a Ritchie tension balance AFB (see Fig. 48). The fulcrum F being at the center, the two wires are under equal tension. A micrometer screw. Three bridges.

The diagram shows a horizontal wire stretched between two points, A on the left and B on the right. The wire is supported by three bridges. The central bridge is labeled F, which is the fulcrum. To the left of F is a bridge labeled H, and to the right of F is a bridge labeled E. The wire is shown with some sag and is labeled with C and D at the ends near A and B respectively.

Operations. — (1) Measure the diameters of the wires, or obtain them from Table XIII., p. 181, if their numbers are known.

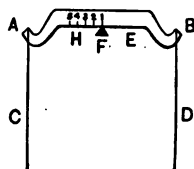


Fig. 49.

(2) Take some measured length of the smaller wire, as 100 cm. (designated by A), and find a length a of the larger wire that will give a note of the same pitch as A .

(3) Repeat the same operation with A equaling successively 90, 80, 70, 60, and 50 cm.

(4) Find the ratio in each case of a to A .

Record the data as follows:—

<i>A.</i>	100 cm.	90 cm.	80 cm.	70 cm.	60 cm.	50 cm.
<i>a</i>	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$
$\frac{a}{A}$						

Average value of $\frac{a}{A}$ = -----

D = ----- d = ----- Value of $\frac{d}{D}$ = -----

Explanations. —

Let A = length of the smaller wire.

Let a = length of the larger wire having the same pitch
as length A of the smaller wire.

Let V = vibration rate of smaller wire of a length A .

Let v' = vibration rate of larger wire of a length a .

Let v = vibration rate of larger wire of a length A .

Let d = diameter of the smaller wire.

Let D = diameter of the larger wire.

By the preceding exercise, $\frac{v}{v'} = \frac{a}{A}$. Since V and v' are made to give the same pitch, $V = v'$, and hence can be substituted for it in the above equation, which becomes $\frac{v}{V} = \frac{a}{A}$.

Hence $\frac{a}{A}$ expresses the ratio of the vibration rates of the two wires of equal length and tension. Compare it with $\frac{d}{D}$.

NOTE. — Since the volumes of the two wires, the lengths being equal, are to each other as the squares of their diameters, their weights must be also. Hence, $\frac{d}{D} = \sqrt{\frac{w}{W}}$, w and W being the respective weights of equal lengths of the two wires. What is the relation between the vibration rates of the two wires and their weights?

EXERCISE LV

VIBRATION OF STRINGS: LAW OF TENSION

Apparatus. — A sonometer fitted with a Ritchie tension balance and two strings of piano wire of the same diameter. Three bridges. A verniered caliper (Fig. 7, p. 28), or dividers and diagonal scale.

EXERCISE LVI

VIBRATION RATE OF A TUNING-FORK

Apparatus.—A tuning-fork making from 100 to 250 vibrations per second. A pendulum of a known rate of vibration, and arranged to make and break an electric circuit at every swing by a mercury contact. A relay. An induction coil. Two batteries. An apparatus, shown in Fig. 50, in which

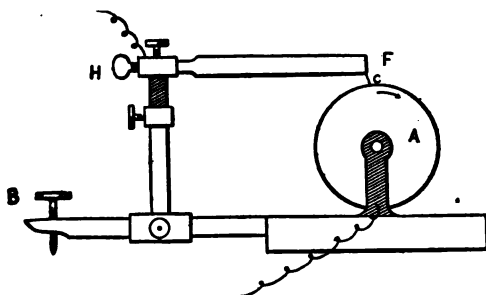


Fig. 50.

A is a metallic drum, about 12 cm. in diameter and 15 cm. long, supported on a shaft that has a crank at one end. A thread is cut on one end of this shaft, so that when the drum is revolved it moves longitudinally. A small flexible point *c* is cemented to the end of one of the prongs of the fork *HF*, a piece of an old hair-spring from a watch being used for it. A bass-viol bow. A candle or an ordinary gas-jet.

Operations.—(1) Gum one end of a strip of paper long enough to reach around the drum, and as wide as the drum is long, and fasten it tightly around the drum.

(2) Smoke the paper evenly and thinly by holding a

candle flame, or a gas-jet from a fish-tail burner, against it, and revolving the drum rapidly.

(3) Fix the fork in position so that the point *c* just touches the paper. The screw *B* affords a fine adjustment for this purpose. This adjustment should be made with great care.

(4) Connect one terminal of the secondary of the induction coil with the fork, and the other with the drum. Connect the primary of the coil with the battery and with the contact maker of the relay, and the relay coil with the other battery and the pendulum. The induction coil and the battery used with it must be large enough to produce a spark at *c* to penetrate the paper at each swing of the pendulum. Turn the screw up against the vibrator of the induction coil so that it cannot vibrate.

(5) Set the fork in vibration by the bow, and turn the drum with a steady motion in the direction shown by the arrow. Turn the drum so that there will be at least two sparks at every revolution.

(6) Remove the paper from the drum by cutting it across near the lap, being careful that the smoked surface does not touch anything. Pass the paper through shellac varnish, and when it is dry count the number of vibrations from one hole in the paper to the next but one; that is, the number made during one complete vibration of the pendulum. It is almost impossible to adjust the pendulum so that the times taken for the swing of the pendulum on each side of the mercury contact will be equal to each other; hence the necessity for counting the vibrations for two half-periods. It will assist the counting to mark every tenth vibration.

Dividing the number of vibrations counted by the time of one complete vibration of the pendulum will give the number of vibrations of the fork per second.

Several trials can be made on one paper. Record the results of two or three trials, and take the average of the several results. Fasten the paper in your note-book.

EXERCISE LVII

VELOCITY OF SOUND

References. — G. & S., pp. 226–229.

Apparatus. — A tuning-fork of a known rate of vibration — 200 to 300 vibrations per second. A thermometer. Two of the glass cylinders used in Exercise XVII.

Operations. — (1) Set the fork in vibration, and hold it over and very near the mouth of the cylinder. With the fork in this position pour water slowly into the cylinder until the air column strongly reinforces the sound of the fork.

(2) The length of the air column reinforcing the fork having been found approximately by the use of a single cylinder, a more exact determination can be made by using two cylinders side by side. Fill the second cylinder until its air column is about $\frac{1}{2}$ cm. longer or shorter than the first. Then hold the vibrating fork first over one, then over the other, determining which one reinforces the fork best, being careful to have the ear equally distant from both cylinders. By comparing two air columns in this way, one being a trifle longer than the other, it is easy to tell whether the air column should be shortened or lengthened to improve the reinforcement.

(3) Change the depth of water in that cylinder that reinforces the fork the least, making it about $\frac{1}{2}$ cm. longer or shorter than the other, according to the indications given above. Proceed in this way, changing first one air column and then the other, until that length is found that best reinforces the fork. Find the average of several determinations.

- (4) Measure the internal diameter of the cylinder.
- (5) Take the temperature of the air in the cylinder.

Record the data in a suitable table.

Calculations. — Add two-fifths of the diameter of the cylinder to the length of the air column found; this will be one-fourth of the wave length produced by the fork. Multiplying the whole wave length by the vibration rate of the fork will give the velocity of sound for the temperature taken.

Compare the velocity thus obtained with that stated in the text-book, *i.e.* 332 m. per second at 0° C. Correct this for temperature by adding to it 0.6 m. for each degree C. above zero, before making the comparison.

Find the percentage of error.

NOTE. — Assuming the velocity of sound to be known, then the vibration rate of the fork can be determined by the above method.

EXERCISE LVIII

VELOCITY OF SOUND IN BRASS: KUNDT'S METHOD

References. — Gt., p. 256; Tyndall's Sound, pp. 193–196, 230–237.

Apparatus. — A glass tube (Fig. 51) about 1 m. long and 3 cm. in diameter, closed at one end with a cork, or, better,

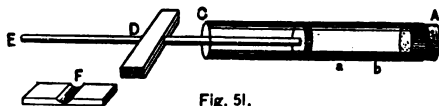


Fig. 51.

with a tightly fitting piston that can be moved into or withdrawn from the tube by a rod. A brass rod *E*, about 60 cm. long and 0.6 cm. in diameter, having a thin cork disk fastened

to one end. The diameter of this disk should be slightly less than the internal diameter of the tube. Some fine dry cork dust made by rubbing a cork upon sandpaper. A clamp *D* for holding the brass rod, made of two strips of wood about 15 cm. long, 2.5 cm. wide, and 1.5 cm. thick, each stick *F* having a shallow groove across one side for the rod to lie in. An iron clamp. A piece of damp cotton cloth, or a dry one with powdered rosin upon it.

Operations. — (1) Clamp the brass rod at its center by placing it between the strips of wood and fastening this wood clamp firmly to the table by the iron clamp. The rod should be parallel to the top of the table, and raised just enough above it to allow the cork disk at its end to pass into the large glass tube without touching the sides of the tube, the latter resting on the table.

(2) Distribute evenly along the inside of the tube a small amount of cork dust and then place it so that the brass rod shall extend into it about 25 cm., the disk not touching the sides of the tube.

(3) Stroke the rod from the center, towards its free end, with the cloth. It will give a high, clear note; and when the air column between the disk and the closed end of the tube is of the proper length, it will set the cork dust into violent agitation.

(4) Vary the length of the air column either by changing the position of the cork disk or the piston in the other end of the tube, until the agitation of the dust is greatest. It will gather into groups of parallel ridges with unoccupied spaces between the groups. When the air column is properly adjusted in length, there will be an exact whole number of these groups, all of equal length. If the adjustment is not exact, the two end groups may not be perfect.

(5) Measure the length of the air column from the disk to the cork and count the number of groups. The length

measured, divided by the number of groups measured, will give the length of one group. If the end groups are imperfect, do not measure or count them.

(6) Measure the length of the brass rod.

(7) To find the velocity of sound in glass, substitute a thick-walled glass tube about 1 m. long and 1 cm. in diameter for the brass rod, and repeat the above operations. The velocity of sound in wood, iron, or other substances can be found by the same method.

The average of several determinations should be taken.

Explanation. — When the rod is set in vibration, the same rate of vibration is communicated to the air of the tube, and the sound is reinforced by the air column. There are as many vibrating air columns as there are *groups* of cork-dust ridges. The points midway between the different groups are places of no vibration, or nodes. As in the previous exercise the distance from the water, or place of no vibration, to the mouth of the tube, or place of greatest vibration, is one-fourth of a wave length; so in this, the distance from a node to the middle of a group is one-fourth of a wave length, or the distance from one node to the next is one-half of a wave length in air. Likewise the distance from the center of the brass rod to its end is one-fourth of a wave length in brass, or the whole rod is one-half a wave length long. Hence the wave length in brass for a given rate of vibration will be as many times as long as a wave length in air for the same rate of vibration as the length of one group is contained in the length of the rod. This ratio of wave lengths will also be the ratio of velocity of sound in brass to that in air. Calculate the velocity of sound in air for the temperature taken, as in the last exercise, and then from the data of this exercise calculate the velocity of sound in brass.

CHAPTER VII

LIGHT

EXERCISE LIX

PHOTOMETRY: RELATION OF INTENSITY OF LIGHT AND OF CANDLE POWER TO DISTANCE

Apparatus.—A Bunsen photometer, which consists essentially of a disk of unsized paper with a grease spot at its center. Two mirrors are usually placed, one on each side of the disk, so that both sides of it can be seen simultaneously. Two blocks, each capable of holding four candles. Some candles of the size called "sixes." An optical bench, consisting of two meter-sticks fastened end to end on a board; or the exercise may be conducted by placing the photometer and candles on a long table. The photometer support and candle blocks should be notched so as to slide along the meter-sticks. A darkened room.

Operations.—(1) Place the candles upon the bench with the photometer between them, having an unequal number of lighted candles on the two sides, as 3 and 2, or 4 and 3.

(2) Place the two sets of candles some exact distance apart, say 150cm., recording the distance under *S* in the table.

(3) By moving the photometer to and fro, find such a position for it that its disk is illuminated equally on both sides. This will be the case when the center of the disk has the same, or nearly the same, appearance as the whole disk; or when its two sides appear alike in the two mirrors.

(4) When the correct position for the photometer is found, record the distances from the disk to the candle flames on each side.

Record the measurements for ten different trials, having the larger number of candles on the right during half of the trials and on the left for the remaining trials.

Record the data as follows:—

$N = \dots\dots\dots n = \dots\dots\dots S = \dots\dots\dots$			
Trials	d	D	
1			Average of d squared = ...
2			Average of D squared = ...
3			$\frac{d^2}{D^2} = \dots\dots\dots$
4			$\frac{i}{I} = \dots\dots\dots$
5			$\frac{n}{N} = \dots\dots\dots$
6			Error
7			Per cent. of error.....
8			
9			
10			
Average,			

Let S = distance between two sets of candles.

Let n = smaller number of candles.

Let N = larger number of candles.

Let d = distance from n candles to photometer.

Let D = distance from N candles to photometer.

Let i = intensity of one of the N candles at distance D .

Let I = intensity of one of the n candles at distance d .

Let Q = intensity of n , or N , candles on the photometer.

It is obvious that one candle would give only one N th as much light as N candles, and one n th as much as n candles, hence

$i = \frac{1}{N}Q$, and $I = \frac{1}{n}Q$. What, therefore, is the value of the ratio $\frac{i}{I}$?

Can you, with this ratio and another in the table, make a proportion? If so, what kind of a proportion, direct or inverse? Why? What, therefore, is the law for intensity of light?

Again, since n and N stand for the number of candles, they represent candle-power. Can you, with the ratio $n:N$, and another in the table, form a proportion? If so, is it direct or inverse? Why?

What, therefore, is the law for candle-power?

EXERCISE LX

TO MEASURE THE CANDLE-POWER OF A LAMP

Apparatus. — Same as for the last exercise. .

Operations. — (1) Substitute the lamp whose candle-power is to be measured for the four candles, placing the flat side of the flame toward the photometer; and proceed as in the last exercise.

Calculations. — In the proportion finally obtained in the last exercise, find the value of N , using the data just obtained. This will be the candle-power of the lamp. Why?

In like manner find the candle-power of the lamp when the edge of the flame is toward the photometer.

EXERCISE LXI

LAW OF REFLECTION OF LIGHT

Apparatus. — A piece of thin looking-glass about 5×8 cm. fastened to the side of a square block. A large sheet of paper. A protractor. Some pins.

Operations. — (1) Fasten a sheet of paper upon the table, or upon a drawing-board, and draw a line MN (Fig. 52), near one edge of it. Place the block B so that the mirror attached to it shall be perpendicular to the paper, and the edge of its silvered surface shall lie exactly on the line MN .

(2) Placing the eye on a level with the paper, set a pin, 1, about 20 cm. from the mirror and a little to one side, so that its image can be seen in the mirror.

(3) Set a pin, 2, in the paper between the eye and

the image of the first pin, and then another pin, 3, in the same line, so that the second and third pins and the image of the first pin shall be exactly in a straight line. In setting the pins, incline them slightly and sight along the surface of the paper, not near the heads of the pins.

(4) Remove the mirror and draw a line through the second and third pins to the line MN , and a line through the first pin to this intersection. Erect a perpendicular to MN at this point.

(5) The angle between this perpendicular and the line to the first pin is the angle of incidence, and the angle between it and the line to the second and third pins is the angle of reflection. Measure these angles by a protractor.

(6) Repeat the above operations two or three times, taking different positions for the pins each time.

Record the data as follows: —

Angle of Incidence.	Angle of Reflection.	Error.	Percentage of Error.
1	1	1	1

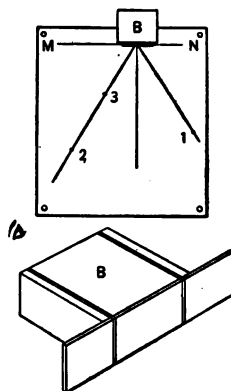


Fig. 52.

EXERCISE LXII

POSITION OF AN IMAGE IN A PLANE MIRROR

Apparatus. — The same as in the last exercise.

Operations. — (1) Draw the line MN across the center of the sheet of paper instead of near one side, and place the mirror upon it, as in the last exercise.

(2) Set the first pin as in the last exercise, marking its position B . Then find three lines in which its image can be seen, proceeding as in the last exercise, and keeping the first pin in the same position.

(3) Since the image of the first pin can be seen in each of these lines, it must be at their intersection. Remove the mirror and draw the lines, extending them back of MN until they meet in a common point. If they do not do so, repeat the operations again more carefully. Mark this point of intersection C .

(4) Draw a line from B to C . How does the line MN divide this line? What angle do the lines MN and BC make with each other? What kind of an image was formed? Why?

(5) Using the law of reflection, prove geometrically the correct position for C .

Preserve the sheet of paper and fasten it in your note-book.

EXERCISE LXIII

FOCAL LENGTH OF A CONCAVE MIRROR

References. — G. & S., p. 338.

Apparatus. — An optical bench. A simple microscope having a focal length of 2 or 3 cm., a pocket magnifier

can be used. A concave mirror about 3 cm. in diameter. If a larger one is used, all but the central portion should be covered with a screen. A fine sewing needle with a tiny loop of white thread in its eye.

The mirror should be attached to a block sliding on the optical bench so that its principal axis shall be parallel to the meter-stick of the bench. The microscope should be fastened to another block so that its principal axis shall coincide with that of the mirror. The needle should be set in the block to which the microscope is attached so that its eye with the loop of thread shall be at the focus of the microscope.

Operations. — (1) Place the blocks upon the optical bench so that the observer, on looking through the microscope at the needle, shall be looking toward the mirror.

(2) Carefully focus the microscope on the needle and its loop of thread. The loop should be very near the center of the field of view.

(3) Find, by moving the microscope block back and forth on the bench, a position for it such that, on looking through the microscope toward the mirror, an inverted image of the needle shall be seen near the needle itself. Move the block back and forth until the image is as distinct in outline and appears as large as the needle itself.

If such a position for the block cannot be found, it is probably due to the fact that the mirror is not placed so as to bring the image of the needle into the field of the microscope. To remedy this, remove the microscope from its block and adjust the mirror so that the image of the needle shall appear close by the needle itself, when looking at the needle in the direction of the vertex of the mirror. The correct position for the needle can be found approximately by the method of parallax described in Exercise LXV., (2). Replace the microscope and determine the position more

exactly. Since both the needle and its image are at the focus of the microscope, they must be equally distant from the mirror and at its center of curvature.

(4) Measure carefully the distance from the mirror to the needle. If the distance is not too great, this can be done by a pair of dividers. The thickness of the mirror should be added to this measurement.

Take the average of several determinations.

When the object is at the center of curvature of the mirror, what is the character of the image formed? How is the focal length of the mirror to be found from the measurement taken above?

EXERCISE LXIV

FOCAL LENGTH OF A CONVEX LENS

A. BY DIRECT SUNLIGHT

Apparatus.—An optical bench 1 m. long. A small convex lens. A small screen of white cardboard or ground glass. The screen and lens should be supported on blocks arranged to slide along the meter-stick of the optical bench.

Operations.—(1) Place the lens and screen upon the optical bench, having the plane of the screen normal to the meter-stick, and the axis of the lens parallel to it.

(2) Place the apparatus in a beam of sunlight so that the rays of light shall be parallel to the meter-stick, and, passing through the lens, shall be received on the screen.

(3) Move the screen back and forth until a position is found for it in which a small well-defined image of the sun is formed upon it.

(4) Measure the distance from the lens to the screen. Repeat the operation several times, and take the average of the several measurements as the focal length of the lens.

B. BY A DISTANT OBJECT

Apparatus. — The same as for the preceding experiment.

Operations. — (1) Place the apparatus in a dark corner of the laboratory in such a position that it shall point through the window toward some distant object, such as a church spire or a chimney.

(2) Find a position for the screen in which a distinct image of the distant object is formed upon it.

(3) Measure the distance from the lens to the screen, taking the average of several trials as the focal length of the lens.

EXERCISE LXV

FOCAL LENGTH OF A CONVEX LENS

BY PARALLAX

Apparatus. — Substitute for the screen used in the last experiment another of wood having a circular opening in it about 3 cm. in diameter, across the center of which two fine wires are fastened, one being horizontal and the other vertical.

Operations. — (1) Support the apparatus so that as you sight through the screen and the lens, the image of some distant object can be seen. The screen should be between the eye and the lens and not more than 30 cm. from the eye during the experiment.

(2) Move the lens along the meter-stick until the image it forms of the distant object coincides with the wire on the

screen. To find this position, move the head to and from side to side. If the image is farther from the eye than the wire is, it will appear, *relatively to the wire*, to move in the same direction as the eye moves. If the image is nearer the eye than the wire is, it will appear to move, *relatively to the wire*, in an opposite direction to that of the eye. In this case move the lens away from the eye; in the first case the lens should be moved toward the eye. When the wire and the image coincide, there will be no motion of the two with respect to each other on moving the eye.

(3) Measure the distance from the lens to the wire, taking the average of several trials for the focal length of the lens.

EXERCISE LXVI

FOCAL LENGTH OF A CONVEX LENS

BY USE OF A TELESCOPE

Apparatus. — A lens whose focal length is to be measured. A small telescope. A stand to support the telescope. An optical bench with two sliding blocks, one to support the lens and the other to carry a paper scale, or a card with fine print upon it.

Operations. — (1) Focus the telescope upon some distant object. It will then be focused for parallel rays. Why?

(2) Set the telescope at the end of the optical bench and support the lens close in front of its object glass so that you can look through the telescope and the lens, at the scale, or card, on the other sliding block.

(3) Move the block carrying the paper scale, or card, back and forth until the scale, or the print, can be clearly seen through the telescope and lens. When this position is

found, place the scale, first, too far away from the lens, and bring it gradually up to the point of distinct vision; and then place it too near the lens, and move it gradually back to the point of distinct vision. Take a point midway between these two positions thus found for the correct position. Find the average of several trials.

(4) Measure the distance from the scale to the lens. If it is a double convex lens, add one-half its thickness to the distance; if it is a plano-convex lens, measure from the screen to the curved surface of the lens. This will be the focal length of the lens.

Since the telescope is focused for parallel rays, what is the direction of the rays that come from the scale after they pass through the lens? How do rays diverging from the principal focus of a lens, and passing through the lens, emerge from the lens? Why is the distance measured above the focal length of the lens?

This method, while a most excellent one for all lenses, is especially adapted to the measurement of the focal length of weak lenses.

EXERCISE LXVII

FOCAL LENGTH OF A CONVEX LENS

BY CONJUGATE FOCI

Apparatus. — An optical bench. The lens and the two screens used in the three preceding exercises. A lamp.

Operations. — (1) Place the screens upon the optical bench a meter or more apart, and place the lens between them.

(2) Place the lamp immediately back of the screen with the opening, having the flame in line with the center of the opening and the center of the lens.

(3) Find by trial a position for the lens between the screens that will give a distinct image of the wires upon the cardboard screen.

(4) Measure the distance from the lens to each screen.

(5) Repeat the operations several times, lessening the distance between the two screens about 10 cm. each time.

Let F = the focal length of the lens.

Let a = distance from the lens to the wires.

Let b = distance from the lens to the image.

The focal length is found by the following formula: —

$$\frac{1}{F} = \frac{1}{a} + \frac{1}{b} \text{ or } F = \frac{ab}{a+b}.$$

Record the data as follows: —

Trials.	$a + b$.	a .	b .	$a \times b$.	F .
1	1	1	1	1	
2					
3					
etc.					
Mean value for F -----					

EXERCISE LXVIII

CONJUGATE FOCI

Apparatus. — Two convex lenses, one, A , large and preferably of long focal length; the other, B , about 8 cm. in diameter. The focal length of B should be known. A

movable white screen. A beam of sunlight. The room somewhat darkened.

Operations. — (1) Allow the sunlight to enter the room through *A*. The rays will be converged approximately to a point *C*, and crossing there will continue on, forming a diverging pencil from that point. It is this diverging pencil of light that is to be used in this experiment; and *C* is to be regarded as the source of light, since the rays diverge from *C* as if they originated there. The lens *B* is to be placed in this pencil so that the light from *C* can pass through it.

(2) Make the distance from *B* to *C* successively (*a*) more than twice the focal length of *B*, (*b*) just twice the focal length, (*c*) more than the focal length, but less than twice the focal length, (*d*) just the focal length, and (*e*) less than the focal length of *B*.

(3) In each case, if possible, find a position for the screen on the opposite side of *B* where the rays are converged to a point *D*, again. It is advisable to have the lens *B* set in the opening of a screen so that no light can pass by its edges. In the cases (*d*) and (*e*) receive the light on the screen, and compare the diameter of the spot of light on it when *B* is removed from the opening of its screen with that of the spot when *B* is present.

(4) Measure the distances *BC* and *BD*, if possible, in each case. If *B* is double-convex, its *optical center*, the point from which the measurements are to be taken, is at the center of the lens; if it is plano-convex, this point is on its convex surface.

(5) Repeat the above operations, making the distances *BC* equal to those found for *BD*. Are the points *C* and *D* interchangeable?

(6) Draw diagrams on a scale one-tenth of the actual dimensions obtained, showing how the lens *B* affects the rays in the five cases of paragraph (2).

Record the data as follows:—

FOCAL LENGTH OF <i>B</i> -----		
<i>BC.</i>	<i>BD.</i>	Direction of Rays.
1	1	$1\frac{1}{4}$

In last column state whether the rays are converging, diverging, or parallel after they pass through *B*.

EXERCISE LXIX

IMAGES FORMED BY A CONVEX LENS

Apparatus.—A convex lens supported on a stand, its focal length being known. A screen. A candle or a lamp.

Operations.—(1) Place the lens between the candle and the screen, having the flame and the centers of the screen and lens in the same horizontal line.

(2) Make the distance from the lens to the candle successively (*a*) more than twice the focal length, (*b*) just twice the focal length, (*c*) more than the focal length, but less than twice the focal length, (*d*) just the focal length, and (*e*) less than the focal length of the lens.

(3) In each case, if possible, find a position for the screen where a distinct image of the flame is formed upon it.

(4) In each case measure the distance from the lens to the flame and the lens to the image. Compare the image with the flame as to size, and state whether it is erect or inverted, virtual or real.

Is there any similarity as to the relative positions of flame and image in this exercise and the foci in the last exercise?

EXERCISE LXX

INDEX OF REFRACTION OF WATER

Apparatus.—A square battery jar, one side of which is covered with a paper having upon it a circle graduated in degrees. The paper within the circle is removed and its vertical and horizontal diameters are marked by lines on the glass, made by a glass cutter or by threads cemented across the circle (see Fig. 53). The graduation should begin with

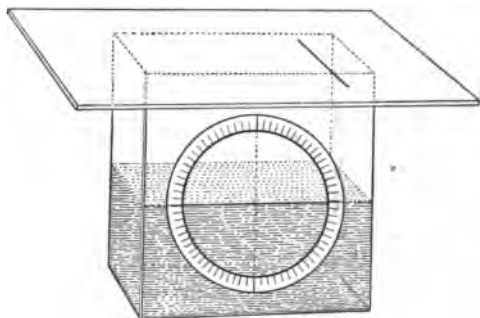


Fig. 53.

zero at the ends of the vertical diameter and end with 90 at the extremities of the horizontal diameter. An alcoholic solution of gum mastic. A piece of cardboard considerably larger than the top of the jar, in which there is a slit about 2 mm. wide and 10 cm. long. A small mirror supported on a stand. The experiment can best be performed in a room somewhat darkened.

Operations.—(1) Fill the jar with water exactly to the horizontal diameter and add a few drops of the gum mastic solution. See that the surface of the water coincides with the diameter along its entire length. Use the method de-

scribed in Exercise XVII., Fig. 20, for observing the position of the surface of the water.

(2) Place the cardboard over the top of the jar with the slit at right angles to the graduated circle ; and, using direct sunlight or a beam from the port-lumière or the lantern, send light through the slit by means of the mirror so that it will strike the water exactly at the center of the circle.

(3) Read the angle of incidence and the angle of refraction by the graduated circle. If the slit extends over the side of the jar a little, so that a part of the ribbon of light just grazes the graduated circle on the outside, the angle of incidence can be read more easily. Read at the center of the edge of the ribbon of light.

(4) Change the angle of incidence by a new adjustment of the positions of the jar, cardboard, and mirror, and repeat the measurements. Take measurements for several different incident angles.

Let I represent the angles of incidence, and R the angles of refraction.

Record the data as follows : —

Trial.	<i>I</i> .	<i>R</i> .	Sin of <i>I</i> .	Sin of <i>R</i> .	$\frac{\text{Sin of } I}{\text{Sin of } R}$.
1 2 3 Etc.	$\frac{3}{4}$	$\frac{3}{4}$	1	1	1

Average value found for the index	-----
Accepted value (Table XVI., p. 182)	-----
Error	-----
Percentage of error	-----

For an explanation of the sine of an angle, see p. 152; and for the values of the sines of angles, see table, p. 182.

EXERCISE LXXI

ANGLE OF A PRISM

References. — G. & S., p. 321.

Apparatus. — A prism whose angle is to be measured. A protractor. A small drawing-board. A sheet of paper at least 25 cm. square. Some thumb-tacks and some pins.

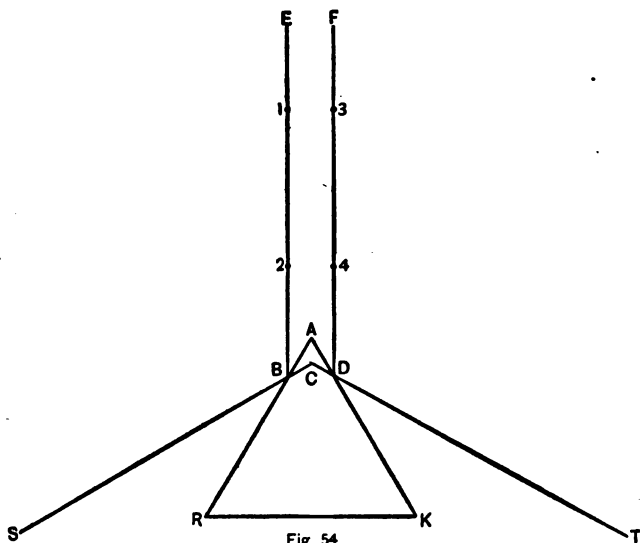


Fig. 54.

Operations. — (1) Fasten the sheet of paper to the drawing-board by the thumb-tacks.

(2) Draw two parallel lines, EB and FD , from the middle of one side to the center of the sheet about 1 cm. apart; and set the prism with the angle A to be measured between the lines, as shown in the figure (see Fig. 54).

(3) Set two pins in each of the parallel lines at positions 1, 2, 3, and 4, pin 1 being 15 or 20 cm. from the prism and about 10 cm. from pin 2.

(4) The pins 3 and 4 can be seen reflected in the side of the prism AK ; and 1 and 2, in the side AR . Find the lines of reflection DT and BS , as in Exercise LXI.

(5) Remove the prism and extend the lines SB and TD till they meet at C , and measure the angle SCT by the protractor.

(6) Repeat the operation several times, finding the average of the several results.

Remarks. — The sheet of paper may be tacked to the table instead of to a drawing-board, but it is better to have it on a board that can be moved about so that the pins 1, 2, 3, and 4 may be turned toward the light during the operation. Care must be taken that the prism is not moved from its position on the paper during the work. A small piece of black cardboard placed back of the prism will assist the eye in sighting the images of the pins.

Explanation. — The angle RAK is one-half of the angle SCT . The proof is as follows: By the law of reflection $EBA = SBR = ABC$; hence AB bisects the angle EBC , and AD the angle FDC . By geometry $RAK = EBA + FDA$; to prove this, extend RA till it intersects FD . Likewise $SCT = EBC + FDC$. But EBA is half of EBC and FDA half of FDC , therefore $RAK = \frac{1}{2} SCT$.

EXERCISE LXXII

INDEX OF REFRACTION OF GLASS

References. — G. & S., pp. 333, 334; K., p. 154.

Apparatus. — A prism whose angle A has been determined. A protractor. A small drawing-board. A sheet

of paper about 25 cm. square. Some thumb-tacks and pins.

A small piece of black cardboard.

Operations. — (1) Fasten the sheet of paper on the drawing-board with thumb-tacks, and set a pin near one corner of the sheet. Call this pin No. 1 (see Fig. 55).

(2) Place the prism near the center of the sheet, and 10 or 15 cm. from pin No. 1, the prism having a position relative to the pin somewhat as shown in the figure. The faces of the prism must be normal to the paper.

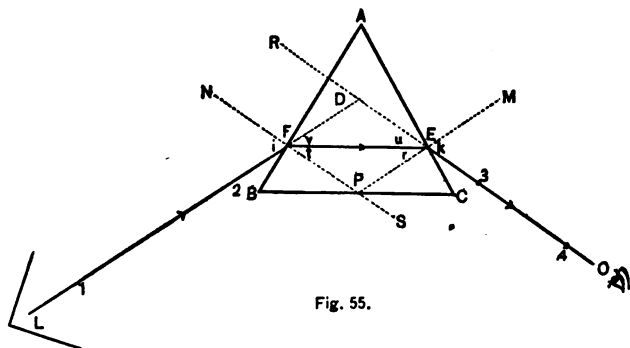


Fig. 55.

(3) Placing the eye on a level with the board, and looking through the prism, the observer will see the pin, if the prism is rightly placed, in the direction *OER*. The pin will appear red on one side, and blue on the other. The pin should be strongly illuminated by light coming in from a window back of the observer, and a piece of black cardboard bent at right angles should be set back of the pin for a background.

(4) While observing the pin in this way, place pin No. 2 2 or 3 cm. from the prism, so that it shall appear to be between the eye and pin No. 1.

(5) The angle *LDR* is the angle of deviation. By twist-

ing the prism about on a vertical axis, a position can be found for the prism, in which this angle will have its smallest value, called the **angle of least deviation**. Of course this will occur when the angle ODL is the greatest. When it is found, light from pin No. 1 will enter the prism at F , pass through in the direction FE , making equal angles with AB and AC , and emerge from the prism in the direction EO . The angle LFN will equal the angle MEO .

When the correct position for the prism is found, turning it in either direction will throw the image of pin No. 1 toward the angle A of the prism.

(6) Place pins 3 and 4 so that they shall be in line with 1 and 2 as seen through the prism. When the pins are all placed, turn the prism to and fro on its vertical axis, to make sure that you have obtained the angle of least deviation.

(7) With a sharp pointed pencil draw an outline about the base of the prism; and then remove the prism, and placing a thin-edged ruler against the pins, draw the lines LD and ODR .

(8) Using a protractor, measure the angle LDR , or D , which is the *angle of deviation*. Determine the angle D several times, and take the average of the results.

Explanation. — MP and NP are normals to the refracting surfaces AC and AB ; and hence the angle between them, $MPS = A$. But $MPS = t + r$, hence $A = t + r$. But $t = r$ when the angle of deviation is least; and hence $A = 2t$, or

$$(1) \quad t = \frac{1}{2} A.$$

That is, *the angle of refraction t equals one-half of the refracting angle of the prism A .*

The angle $D = v + u$, but $i + k = v + u + t + r$. Substituting D for $v + u$ and A for $t + r$, we have $i + k = D + A$; and since $i = k$, we have $2i = D + A$, and

$$(2) \qquad i = \frac{1}{2} (D + A).$$

That is, *the angle of incidence i equals one-half of the sum of the angle of deviation D , and the refracting angle of the prism*

A . Hence

$$\text{The index of refraction} = \frac{\sin \frac{1}{2} (D + A)}{\sin \frac{1}{2} A}.$$

TANGENT AND SINE OF AN ANGLE

These are trigonometrical terms. Let ABC be an angle. With B as a center, and any convenient radius, as BA , strike an arc cutting the two sides of the angle. From the point

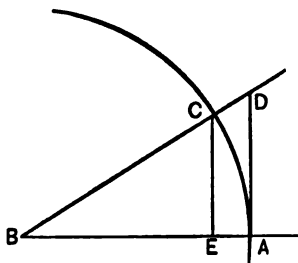


Fig. 56.

where the arc cuts one side, as A , extend a line tangent to the arc, until it intersects the line BC , as at D . The ratio of this line AD to the radius BA , or $\frac{AD}{BA}$, is the **tangent** of the angle ABC . Of course this ratio will be the same whatever the radius may be. It is obvious that

the tangent of an angle of 45° is 1, for the line AD would then equal AB . For angles less than 45° it is less than 1, and for angles between 45° and 90° , it is more than 1, being infinity for 90° .

If a line be drawn from the point where the arc cuts one side, as C , perpendicular to the other side, as CE , the ratio of this line to the radius $\frac{CE}{BA}$ is the **sine** of the angle ABC .

This ratio will obviously be the same whatever the radius may be, but no angle can have a sine greater than 1.

Tables can be found in the back part of any trigonometry giving the tangents and sines of any angle. (See also Table XVII., p. 182). These ratios are called the **natural tangents** and **natural sines**, to distinguish them from the logarithmic sines and tangents.

APPENDIX

Laboratory Equipment.—The necessary fixtures for a physical laboratory are comparatively few. Some plain, substantial tables, about 4 ft. wide and 6 ft. long and 32 in. high, should be provided. These should not be stationary, and should have no iron in their structure. The tops of the tables should project about 3 in. beyond the frames, so that apparatus can be fastened to them by clamps. Gas fixtures should be so placed that gas can be conducted to the tables by rubber tubing, and there should be in the room one or two large sinks with running water.

One teacher ought not to be expected to have charge of more than sixteen pupils in the laboratory, especially if different exercises are being conducted at the same time. It is desirable, on many accounts, that all pupils should be engaged on the same exercise at the same time. This requires the multiplication of apparatus; but by having two pupils work together, as they can advantageously, the difficulty is materially lessened. When it is not possible to furnish sufficient apparatus of one kind for all, it is often feasible to provide enough for one-half or one-third of the pupils, and thus limit the number of exercises at one time to two or three. It is better that the laboratory equipment should grow from year to year, than to attempt to obtain a complete one at the very beginning.

Every teacher of physics should, if possible, be provided with a carpenter's bench and the more common carpenter's tools. He should also have a soldering outfit, an iron vise, a hack-saw for sawing brass and iron, some steel drills, and some taps and dies for cutting screw-threads. A tap and die for cutting what is called an 8-32 thread, and also a quantity of iron and brass 8-32 machine-screws of various lengths, will be found especially useful. These screws can be obtained of the hardware dealer, and will fit nearly all binding-posts in the market. Nuts to fit these screws can also be bought. A quantity of brass rods of various diameters, and of sheet brass of various thicknesses, is very desirable.

If, in addition to all this, the teacher can have a small power or foot lathe, he will be well equipped for repairing and making apparatus. Money so expended is one of the best investments a school board can make.

A JOLLY BALANCE

A simple and useful Jolly balance is easily made. Fasten a board, about 4 in. wide and 30 in. long, to a baseboard for an upright (see Fig. 57). To this upright fasten a piece of looking-glass, about $1\frac{1}{2}$ in. wide and 24 in. long, and paste down its center a narrow strip of paper ruled in millimeters. (Cross-section paper so ruled can be obtained of Keuffel & Esser, New York.) A scale etched on the mirror, of course, would be better. To support the spring, prepare a stick

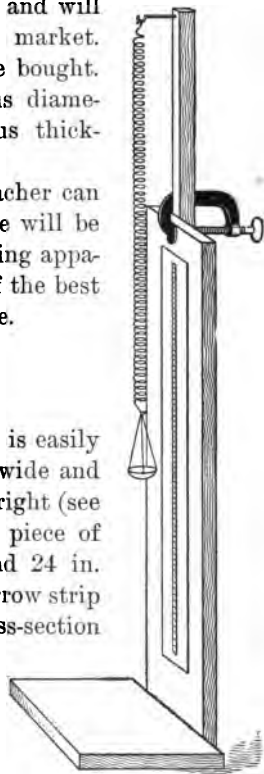


Fig. 57.

about $\frac{3}{4}$ in. square and 2 ft. long, and place through one end of it a small brass rod bent as shown in the figure. This stick can be fastened to the back of the upright board, at any desired height, by an iron clamp, the brass rod extending out over the mirror about 2 in.

To make the springs, procure some spools of spring brass wire, Nos. 21, 22, 24, and 28. For each spring wind from 30 to 40 convolutions of wire, in a neat close spiral, upon a metal rod or a tin tube, about $\frac{1}{2}$ in. in diameter. To fasten the wire to the rod, bore a small hole through the rod near one end, pass the end of the wire through it, and bend it over. About 6 ft. of wire will be required for each spring. Fasten the other end of the wire in a vise, and keep the tension on the wire and the angle between the rod and the wire constant while winding.

Solder a small piece of sheet tin to the end of the spring for an index, and use a tin box cover for a scale-pan.

A SECONDS PENDULUM

If a clock with a seconds pendulum is not to be had, a seconds pendulum can be made by soldering to one end of a brass or iron rod, about 40 in. long, a piece of very thin sheet brass, $\frac{1}{2}$ in. wide and 3 in. long. Suspend this by the brass strip from a bracket on the wall, and place on its lower end a weight of 3 or 4 lb. for a bob. Arrange the bob with thread and nut, as in an ordinary clock, for regulation. The pendulum can be supported at its upper end by placing the brass strip between two small blocks of hard wood, and screwing these blocks together, passing one of the screws through the brass strip.

About halfway up the pendulum, on a second bracket on the wall, a mercury contact should be placed. This can be made of a block of wood about $1\frac{1}{2}$ in. square and $\frac{3}{4}$ in. thick.

Bore a $\frac{1}{8}$ -in. hole through the center of the block from side to side. Close this hole at one end with a short 8-32 machine-screw having a washer upon it, and the other end with a longer screw, driven about halfway in. Bore another hole of the same size as the first in the top of the block just deep enough to intersect the first one. Fill this with mercury. The short screw will serve as an attachment for one of the battery wires, and the long screw will control the elevation of the mercury, causing a globule of it to stand above the surface of the block. The other battery connection should be made to the upper end of the brass strip at the top of the pendulum. To make the contact with the mercury, a piece of thick wire about 2 in. long is soldered to the pendulum just above the mercury contact, and bent so that its end is just above the mercury globule. The end of this wire should be tipped with a short piece of platinum wire, or with a piece of foil about $\frac{1}{8}$ in. wide. This platinum tip should touch the center of the mercury globule when the pendulum is at rest.

Such a pendulum will swing for a long time when set in motion; and with a sounder, electric bell, or relay in the circuit will be useful for both class and laboratory experiments.

A Pendulum Clamp.—The clamp shown in Fig. 17, p. 48, is made of two pieces of brass, each $\frac{3}{4}$ in. wide and $\frac{3}{16}$ in. thick. *a* is 1 in. and *b* 2 in. long. The pin *c* and the screw *e* pass through *b*, and are soldered in place; but the holes through *a* are large enough to allow it to move freely upon *c* and *e*. The thread of the pendulum can be passed over the pin *c*, which may be used as a pulley when changing the length of the pendulum.

Iron Cap for Boyle's Law Apparatus.—This consists of an iron ferrule (Figs. 27 and 28, p. 62) about $1\frac{1}{2}$ in. long, its

inside diameter being about $\frac{3}{8}$ in., or a trifle larger than the outside diameter of the glass tube to be cemented into it. A thread is cut on one end of the ferrule for about $\frac{1}{2}$ in. The glass tube should project through the ferrule nearly $\frac{1}{4}$ in. The cap that screws on to the ferrule is about $\frac{3}{8}$ in. deep, and is lined at the top with a soft leather or rubber washer, which closes the end of the glass tube air-tight when the cap is screwed down.

Sinker for Specific Gravity of Liquids.—Fuse a platinum wire into a piece of glass rod about $\frac{3}{8}$ in. in diameter and 2 in. long. The advantage of such a sinker is that the specific gravity of the liquids can be determined without taking them from the bottles in which they are kept, as the sinker can be lowered into the liquid through the mouth of the bottle.

The Simple Voltaic Cell.—It is often very troublesome to keep the plates of the cell in the proper position. The support shown in Fig. 35, p. 91, is easily made, and is very convenient. Take two brass rods, 8 in. long and $\frac{5}{8}$ in. in diameter, cut a thread on the end of each, and screw them into a board just far enough apart to allow the tumbler to sit between them. Bore a hole through the blocks to which the plates are fastened just a trifle larger than the rod, so that they can slide up and down the rod, but will be kept at any desired height by friction. It is better to bore this hole near one end of the block than at the center.

A Tangent Galvanometer.—By means of a scroll-saw cut out of lumber $\frac{1}{4}$ inch thick, twenty-four pieces of the shape shown in Fig. 58, and of such size that six of them will make a circle whose external diameter is about 30 or 35 cm. These pieces should be 3 cm. wide. Cut twelve more pieces,

4 cm. wide, out of lumber $\frac{3}{8}$ in. thick, and of such size that six of them will make a circle of the same internal diameter as the others. The grain of the wood should run lengthwise of each piece.

Glue the pieces together so as to form a wheel or reel, laying one circle upon another so as to break joints, and placing the wider pieces on the outside to form flanges.

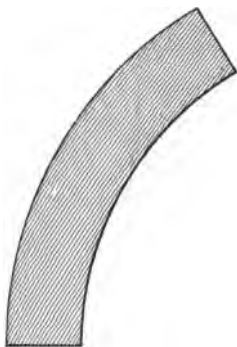


Fig. 58.

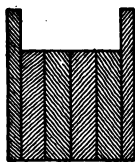


Fig. 59.

Secure the pieces in place by round-headed brass screws. Use no iron about the instrument. Figure 59 shows a cross-section of the reel, one-half size.

Wind upon this reel two turns of No. 14 copper magnet wire for the first coil, then six more turns of the same wire for the second coil, and for the third, fourth, and fifth coils respectively 25, 75, and 150 or more turns of No. 26 copper wire. Wind all of the coils in the same direction, and mark in some way the ends of each coil as it is completed, so that they can be distinguished when the final connections are to be made. It is especially desirable to know the average diameter of each coil accurately, and the exact number of turns of wire in each coil.

If the radius a of a coil in centimeters, the number n of turns of wire in the coil, and the horizontal intensity H of the earth's magnetism are known, then the reduction factor C in amperes can be found by the following formula:—

$$C = \frac{10 Ha}{2 n \pi}.$$

This formula applies to 45° only.

H in the northern part of the United States is about 0.18.

This formula will be found useful in checking the results of Experiments XLIII. and XLIV.

Particular attention must be paid to the insulation of the wires where they emerge from the coils, lest there be any short-circuiting. The first end of the first coil is to be fastened to binding-post No. 1; the last end of the first coil, and the first end of the second coil, is to be fastened to binding-post No. 2, and so on to the last. When so connected, any coil can be used alone or in series with other coils. They should be so connected up that when the first and the last binding-posts are used none of the coils will be in opposition to the rest.

The reel is to be mounted on a circular base (see Fig. 37), which should be provided with leveling screws. There should be a hole through the center of the base, 3 or 4 cm. in diameter, through which the wires can be passed to the binding-posts. Secure the base and the compass box from a wood turner. The box should be about 5 cm. deep and 12 cm. in diameter. A piece of thick cardboard can be used for the bottom of the box (see Fig. 60). The box should have a glass cover with a hole about 1 mm. in diameter through its center.

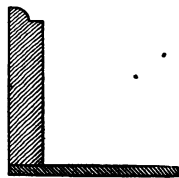


Fig. 60. (Half size.)

To support the compass box, place a bar of wood about 1 cm. below the center of the reel. This bar can be fastened in place easily by a pair of small brass hinges. In the bottom of the box a circular piece of looking-glass should be fitted, to which should be fastened a paper circle graduated in degrees. (These paper protractors can be obtained of the Eberbach Drug and Chemical Co., Ann Arbor, Mich.) For a needle harden a piece of watchspring by heating it red hot and plunging it into cold water; magnetize it, and break off a piece about 1.5 cm. long. Set this edgewise in a disk of elder pith, and cement to this, at right angles to the needle, a pointer of fine wire or of glass, made by drawing out a piece of glass tubing. This pointer must be long enough to extend over the graduated circle, and great care must be exercised in placing it at right angles to the needle. Suspend this needle and pointer in the box by a single fiber of untwisted silk, passing the fiber up through the hole of the glass cover and fastening it to the glass by a bit of cement. The value of the instrument depends largely on the needle being well balanced and well centered, and upon perfect insulation of the wires of the various coils and turns. Silk fiber can be best manipulated over a dark shiny surface like black oilcloth, and by a pair of small forceps with curved points. A small crochet hook is also useful.

In place of the needle described above, a small compass needle with an agate bearing can be used, a thumb-tack being cemented upside down in the bottom of the box for a pivot. This will need a long pointer, at right angles to the needle, the same as the other.

The author has six instruments similar to the one described here, all of which were made by his pupils. One of them was made by two girls.

A Wheatstone Sliding Bridge. — Secure a well-seasoned board about 15 cm. wide and 120 cm. long. Fasten to this, by screws, a strip of sheet copper *BB* (Fig. 61), 2.5 cm. wide and 94 cm. long; also two other strips *AA*, each 12 cm. long. These strips *AA* must be exactly 1 m. apart. Fasten a meter-stick *SS* to the board, and solder a German silver wire, about No. 25, to the strips *AA*, at the points *cc*, so that it shall be parallel to the meter-stick, and about 0.5 cm. from it.

In order to solder the wire in place, it will be found convenient to stretch the wire between two nails driven into the ends of the board, and then to cut the wire off the proper length afterwards. Place binding-posts at

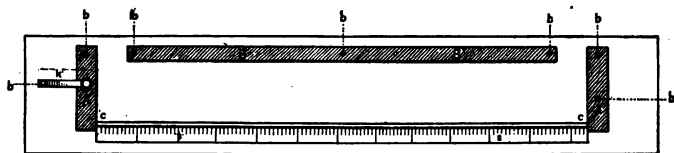


Fig. 61.

the points marked *b*, and a key *k* to connect one of the strips *A* to a binding-post beside it. Be sure that the electrical connection between the binding-posts and strips of copper is perfect and permanent.

The sliding key for the bridge is shown in detail at *C* in Fig. 45, on p. 111. This should be a block about 8 cm. long and 2 cm. square. There should be a groove along its under side, so that it can be moved along against the meter-stick without touching the wire. The contact spring should be held in place by a small binding-post set in the center of the upper side of the block.

A D'Arsonval Galvanometer. — The one shown in Fig. 62 is made of half-inch black walnut. The base is $3\frac{1}{2} \times 6\frac{1}{2}$ in.,

and the inside measurements of the case are $2\frac{1}{4} \times 2 \times 9$ in. The magnet is made of steel $\frac{3}{8} \times \frac{3}{4}$ in., bent into the shape of a horseshoe 5 in. long and $2\frac{1}{4}$ in. wide, or just wide enough to fit into the case, thus leaving a space of $1\frac{1}{2}$ in. between the poles.

A piece of gas pipe 1 in. in diameter and $1\frac{1}{2}$ in. long is placed between the poles, being held in position by a brass

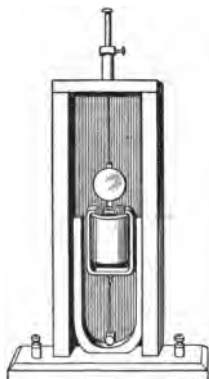


Fig. 62.

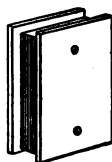


Fig. 63.

machine-screw through the back of the case. A block is placed back of it to bring its center exactly between the poles of the magnet.

The coil is rectangular in form, $1\frac{1}{8} \times 1\frac{3}{4}$ in. interior dimensions, and about $1\frac{3}{8} \times 2$ in. on the outside. This coil should be wound about a copper or brass frame. Make a wooden form (Fig. 63), the middle piece being $1\frac{3}{8} \times 2 \times \frac{1}{4}$ in. Take a piece of very thin sheet copper or brass $\frac{5}{8}$ in. wide and $7\frac{1}{4}$ in. long, and form it into a rectangle that will exactly fit over the middle piece of the form, soldering the ends together. Cut notches in the corners of this and turn up the sides and ends so that it will fit into the wooden form when the sides

are on. Upon this wind No. 36 silk-covered wire, making a coil nearly $\frac{1}{8}$ in. thick. (No. 40 is better, but it is very difficult to wind.) Great care must be taken that the insulation is not injured by the sharp edges of the copper rectangle. Apply a coat of shellac to the wire several times while winding it, and before taking it from the form it should be thoroughly dried in an oven. When it is dry, remove it from the frame and bend the ends and sides of the copper rectangle neatly about the coil.

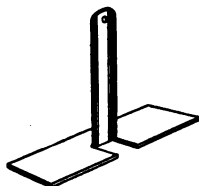


Fig. 64.

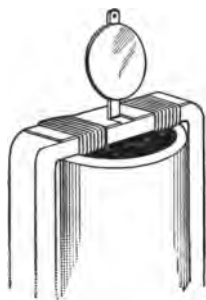


Fig. 65.

This copper frame will help to keep the coil in shape, and will render the instrument more "dead beat."

Cut from thin sheet copper two pieces (Fig. 64), each about $\frac{3}{16}$ in. wide and $\frac{3}{4}$ in. long, with a tongue $\frac{1}{8}$ in. wide and $\frac{3}{4}$ in. long. Solder the ends of the wire of the coil to these pieces, and bind one to the top and one to the bottom of the coil by coarse silk thread, insulating them from the coil by a piece of silk (see Fig. 65). The coil is suspended by pieces of No. 40 copper wire soldered to these tongues. The lower end of the lower wire is soldered to a $\frac{1}{8}$ -in. brass rod $\frac{1}{2}$ in. long, a (Fig. 66), that fits loosely in a hole in a larger brass rod c attached to the instrument by a machine-

screw through the back near the bottom. The connecting wires run from the binding-posts up the back of the instrument, one to the rod *C* (Fig. 66) and one to the cylinder at the top of the instrument (Fig. 62). The upper wire of the coil is soldered to a $\frac{1}{8}$ -in. brass rod 3 in. long, that passes up through this cylinder and is held in place by a set-screw.

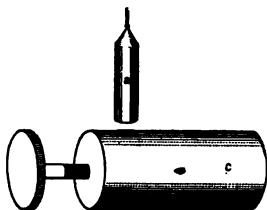


Fig. 66.

The mirror is attached to the tongue at the top of the coil.

Use a plane mirror $\frac{3}{4}$ in. in diameter when using the instrument with telescope and scale in the laboratory. If a concave mirror $\frac{1}{4}$ in. in diameter and about 20 in. focus is placed on the coil, the flame of a lamp, or even of an ordinary candle, can be projected on the wall of the lecture room, thus making a most excellent instrument for class experiments. (Such mirrors can be obtained from the International Optical Lens Co., 272 Jones Street, Detroit, Mich., at 50 to 75 cents each.) The sides of the case are provided with grooves so that a strip of glass can be slid down the front of the case to protect the coil from air currents.

NOTE. — A pasteboard mailing tube about 1 in. in diameter and 1 ft. long can be made to answer fairly well for a telescope, when zero methods are used. Place a pin through one end of the tube, and for an eyepiece place at the other end a cap with a hole in it about $\frac{1}{4}$ in. in diameter. Ordinary telescopes costing two or three dollars can be made to serve every purpose.

Exercise XXXII. : Specific Heat. — Aluminum rods 1 in. in diameter can be obtained through the hardware dealer. For the mass to be used with aluminum calorimeter, cut from such a rod a cylinder about 3 in. long. If a copper calo-

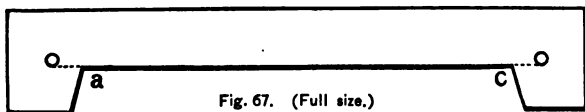
rimeter is used, cut from a copper rod 1 in. in diameter a cylinder about 2 in. long.

Aluminum liquor shakers of about 500 c.c. make excellent calorimeters and can be obtained at very reasonable prices.

The Daniell Cell. — Make up a 5 per cent solution of zinc sulphate, and, when the cell is to be used, fill the porous cup with it, placing the cell on a circuit of a few ohms' resistance for several minutes before using it. The zinc should be thoroughly amalgamated. When the cell is not in use, the zinc sulphate should be turned out of the porous cup, which should be kept in water. Be sure that the copper sulphate solution is kept saturated by always having some crystals in the pocket on the copper plate.

The Siren. — The number of holes in the circles of the disk mentioned in Exercise LII. should be in such proportion that the notes of the musical scale will be produced, beginning with the inner circle and going toward the circumference of the disk. Twenty-four holes is perhaps the best number for the inner circle. A good disk can be made from a sheet of tin.

The Tension Balance for the Sonometer. — Secure a piece of tool steel $\frac{1}{8}$ in. thick, $\frac{1}{2}$ in. wide, and 3 in. long. Bore a



$\frac{1}{16}$ -in. hole near each end (Fig. 67), and cut away the steel on one side so that the edge *ac* shall be in line with the sides of the holes, as shown in the figure. File very shallow

notches in the edge *ac*, as described in Exercises LIV. and LV. For a fulcrum for this balance grind a three-cornered file down to a smooth edge, and set it in the block at the end of the sonometer. The sonometer wires are to be looped through the holes in the balance and fastened at the other ends to piano keys. The balance should be tempered. In measuring the length of the balance arms, measure from the center of the holes to the notches.

A Tuning-fork suitable for laboratory exercises can be made by a blacksmith out of steel $\frac{1}{8}$ in. thick and $\frac{3}{4}$ in. wide. The prongs should be about 6 in. long and should be left soft at the ends, so that they can be filed away for adjustment.

To bend Glass Tubing. — Hold the tube in the flat luminous flame of an ordinary gas burner so that it will be heated for about 3 in. of its length, constantly turning the tube about in the fingers. As soon as it has softened, remove it from the flame and bend it quite quickly. When it is cold, remove the soot by a damp cloth.

Boring Glass. — Use an awl or tool having a rounded wedge-shaped point, — a point much like that of a pegging awl, but much more blunt. Place a piece of thick sheet lead under the glass at the point where the hole is to be bored, and moisten the tool with a solution made of 8 parts by weight of camphor, 16 parts by weight of turpentine, and 3 parts by weight of ether.

By giving a twisting motion to the awl or tool, a hole is quickly and easily made through the glass.

Soldering. — A soldering fluid is made by placing all the zinc that will dissolve in some hydrochloric acid. Add to this solution a little ammonium chloride. In soldering elec-

trical instruments, rosin should always be used instead of this fluid, which will cause corrosion of the parts unless thoroughly washed away. It is usually more difficult to solder with rosin than with the fluid, and a hotter iron is required.

A Useful Cement is made by mixing 1 part of gutta percha and 1 part of pine-pitch at 100° C., stirring it thoroughly together.

Apparatus Supply. — Some of the articles for the apparatus and experiments of this book can be obtained at the following places: —

Cross-section paper in large sheets ruled in millimeters or in fractional parts of an inch: Keuffel & Esser, New York.

Micrometer screws, steel rules, verniered calipers: E. G. Smith, Columbia, Pa.

Metric diagonal scales (metal), micrometer screws for Exercise XXX., paper graduated circles for tangent galvanometers and for Exercise LXX., general physical apparatus: Eberbach Drug and Chemical Co., Ann Arbor, Mich.

Pendulum like that described on p. 155, iron cap for Boyle's law tube, Wheatstone bridge, Jolly balance, D'Arsonval galvanometer, telescope and scale, optical bench: R. H. Miller, Scientific Instrument Maker, Ann Arbor, Mich.

Mercurial barometer such as that used by the United States Weather Bureau, etched mirror scales: Schneider Bros., 265 Greene Street, New York.

Sonometers: Clough & Warren Organ Co., Detroit, Mich.

Small mirrors for galvanometers, and small lenses: International Optical Lens Co., 272 Jones Street, Detroit, Mich.

Aluminum liquor shakers for calorimeters: Sidney Shepard & Co., 145 Seneca Street, Buffalo, N.Y.

Aluminum plate and sheet, wire, tubing, bars, rods, etc.: Pittsburgh Reduction Co., 121 Third Avenue, Pittsburgh, Pa.

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TABLE I

METRIC EQUIVALENTS

1 m.	= 39.37 in. = 3.2809 ft.
1 km.	= 0.62137 mi.
1 in.	= 2.5400 cm.
1 ft.	= 30.480 cm.
1 mi.	= 1.60933 km.
1 sq. in.	= 6.4515 sq. cm.
1 sq. ft.	= 929.01 sq. cm.
1 sq. cm.	= 0.1550 sq. in.
1 cu. in.	= 16.387 c.c.
1 cu. ft.	= 28316 c.c.
1 c.c.	= 0.06102 cu. in.
1 g.	= 15.43235 gr.
1 kg.	= 2.2046 lbs. avoird.
1 g.	= 0.035274 oz.
1 lb. avoird.	= 453.59 g.
1 oz. avoird.	= 28.3495 g.
1 fluid oz.	= 29.571 c.c.
1 liquid qt.	= 0.9463 l.
1 dry qt.	= 1.101 l.

TABLE II

USEFUL NUMBERS AND FORMULAS

$$\pi = 3.1416, \pi^2 = 9.8696, \frac{1}{\pi} = 0.31831, \frac{\pi}{4} = 0.7854, \log \pi = 0.4971499.$$

Circumference of a circle (radius r)	$= 2\pi r.$
Area of circle (radius r)	$= \pi r^2.$
Surface of a sphere (radius r)	$= 4\pi r^2 = \text{diam.} \times \text{circum.}$
Volume of a sphere (radius r)	$= \frac{4}{3}\pi r^3.$
Volume of right cylinder (height h , base πr^2)	$= \pi r^2 h.$

TABLE III

DENSITIES OF SUBSTANCES IN GRAMS PER CUBIC CENTIMETER

Agate	2.615	German-silver	8.432
Alcohol, absolute	0.806	Glass, flint	3.000 to 3.600
Alcohol, common	0.833	Glass, crown	2.520
Aluminum	2.670	Glass, plate	2.760
Antimony, cast	6.720	Glycerine	1.260
Apple-tree wood	0.790	Gold	19.360
Ash, dry	0.690	Gypsum, crys.	2.310
Ash, green	0.760	Granite	2.650
Asphalt	2.500	Graphite	2.500
Beech, dry	0.690 to 0.800	Gun-metal	8.561
Beeswax	0.964	Hydrochloric acid, aq. sol. .	1.222
Bell-metal	8.050	Ice	0.917
Benzine	0.72 to 0.740	Iron, bar	7.788
Birch	0.690	Iron, cast	7.230
Bismuth, cast	9.822	Iron, wrought	7.780
Boxwood	1.280	Iron pyrites	5.000
Brass, cast	8.400	Ivory	1.820
Brass, sheet	8.440	Lead, cast	11.360
Brick	1.6 to 2.000	Lead, sheet	11.400
Cedar, American	0.554	Lignum vitæ	1.333
Chalk	1.8 to 2.800	Limestone	3.180
Cherry	0.710	Mahogany	0.56 to 0.852
Chestnut	0.606	Maple	0.755
Coal, anthracite	1.26 to 1.800	Marble	2.720
Coal, bituminous	1.270 to 1.423	Mercury	13.596
Cork	0.240	Naphtha	0.848
Copper, cast	8.830	Nitric acid	1.38 to 1.559
Copper, sheet	8.878	Oak, American red	0.850
Diamond	3.530	Oak, American white	0.779
Ebony	1.187	Oak, live, seasoned	1.068
Elm	0.579	Oil, turpentine	0.870
Elm, Canadian	0.725	Paraffine	0.824 to 0.940
Emery	3.900	Petroleum	0.836
Ether	0.736	Phosphorus	1.830
Fir, spruce	0.512	Pine, white, dry	0.564
Fluor-spar	3.200	Pine, Norway	0.689
Galena	7.580	Pine, yellow, dry	0.461

TABLE III.—*Continued*

DENSITIES OF SUBSTANCES IN GRAMS PER CUBIC CENTIMETER

Pine, pitch	0.660	Sulphur, native	2.033
Platinum wire	21.531	Sulphuric acid	1.840
Porcelain, china	2.380	Tallow	0.940
Quartz	2.650	Tin, cast	7.290
Saltpeter	2.100	Walnut	0.680
Sand, quartz	2.750	Water, sea	1.027
Silver, cast	10.424 to 10.511	Wax, white	0.970
Slate	2.880	Zinc, cast	7.000
Steel, unhammered	7.816		

TABLE IV

THE DENSITY AND VOLUME OF WATER AT VARIOUS TEMPERATURES

Tempera- ture C.	Volume of 1 g. in c.c.	Density or Mass of 1 c.c.	Tempera- ture C.	Volume of 1 g. in c.c.	Density or Mass of 1 c.c.
0	1.0001269	0.999873	19	1.00158	0.998422
1	1.0000730	0.999927	20	1.00179	0.998213
2	1.0000331	0.999966	21	1.00200	0.998004
3	1.0000083	0.999999	22	1.00222	0.997784
4	1.0000000	1.000000	23	1.00244	0.997566
5	1.0000082	0.999999	24	1.00271	0.997297
6	1.0000309	0.999969	25	1.00293	0.997078
7	1.0000708	0.999929	26	1.00321	0.996800
8	1.0001216	0.999878	27	1.00345	0.996562
9	1.0001879	0.999812	28	1.00374	0.996274
10	1.0002684	0.999731	29	1.00403	0.995986
11	1.0003598	0.999640	30	1.00433	0.995688
12	1.0004724	0.999527	40	1.00773	0.992329
13	1.0005862	0.999414	50	1.01205	0.988093
14	1.0007146	0.999285	60	1.01698	0.983303
15	1.0008751	0.999125	70	1.02255	0.977947
16	1.0010215	0.998979	80	1.02885	0.971959
17	1.0012067	0.998794	90	1.03566	0.965567
18	1.00139	0.998612	100	1.04315	0.958634

1 cu. in. of water at 16 C. weighs 0.577 ounces avoird.

TABLE V

SPECIFIC GRAVITY OF AQUEOUS SOLUTIONS AT 15° C.

The % signifies the weight of the substance (salts are anhydrous) to 100 parts by weight of the solution.

%	NaCl.	CuSO ₄ .	ZnSO ₄ .	AgNO ₃ .	H ₂ SO ₄ .	Alcohol.
5	1.035	1.050	1.052	1.043	1.0334	0.9904
10	1.072	1.103	1.108	1.090	1.0687	0.9831
15	1.110	1.161	1.168	1.141	1.1048	0.9769
20	1.150	(1.225)	1.236	1.197	1.1430	0.9708
25	1.191		1.307	1.257	1.1816	0.9644
30			1.382	1.323	1.2230	0.9565
35				1.396	1.264	0.9485
40				1.479	1.307	0.9390
45				1.572	1.352	0.9287
50				1.677	1.399	0.9179

TABLE VI

ACCELERATION g DUE TO GRAVITY AND LENGTH l OF THE SECONDS
PENDULUMS FOR DIFFERENT LATITUDES

Lat.	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°	90°
g	978.1	978.2	978.7	979.3	980.2	980.62	981.1	981.9	982.6	983.0	983.2
l	99.10	99.12	99.15	99.23	99.31	99.36	99.40	99.49	99.56	99.60	99.62 cm.

TABLE VII
REDUCTION OF BAROMETER READING TO 32° F.

Temperature.	Inches.								
	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0
50	-0.052	-0.053	-0.054	-0.055	-0.056	-0.057	-0.058	-0.059	-0.060
51	0.055	0.056	0.057	0.058	0.059	0.060	0.061	0.062	0.063
52	0.057	0.058	0.059	0.060	0.061	0.062	0.064	0.065	0.066
53	0.060	0.061	0.062	0.063	0.064	0.065	0.066	0.067	0.068
54	0.062	0.063	0.064	0.065	0.067	0.068	0.069	0.070	0.071
55	0.064	0.065	0.066	0.068	0.069	0.070	0.071	0.073	0.074
56	0.067	0.068	0.069	0.070	0.072	0.073	0.074	0.075	0.077
57	0.069	0.070	0.072	0.073	0.075	0.076	0.077	0.078	0.080
58	0.071	0.073	0.074	0.076	0.077	0.078	0.080	0.081	0.082
59	0.074	0.075	0.077	0.078	0.080	0.081	0.083	0.084	0.085
60	0.077	0.078	0.079	0.081	0.082	0.084	0.085	0.086	0.088
61	0.079	0.080	0.082	0.083	0.085	0.086	0.088	0.089	0.091
62	0.082	0.083	0.085	0.086	0.088	0.089	0.091	0.092	0.094
63	0.084	0.085	0.087	0.088	0.090	0.091	0.093	0.095	0.096
64	0.086	0.088	0.090	0.091	0.093	0.094	0.096	0.097	0.099
65	0.089	0.090	0.092	0.093	0.095	0.097	0.099	0.100	0.102
66	0.091	0.093	0.095	0.096	0.098	0.099	0.101	0.103	0.105
67	0.094	0.095	0.097	0.099	0.101	0.102	0.104	0.106	0.108
68	0.096	0.098	0.100	0.101	0.103	0.105	0.107	0.108	0.110
69	0.099	0.100	0.102	0.104	0.106	0.107	0.110	0.111	0.113
70	0.101	0.103	0.105	0.106	0.109	0.110	0.112	0.114	0.116
71	0.103	0.105	0.107	0.109	0.111	0.113	0.115	0.116	0.119
72	0.106	0.108	0.110	0.112	0.114	0.116	0.118	0.120	0.122
73	0.108	0.110	0.112	0.114	0.116	0.118	0.120	0.122	0.124
74	0.111	0.113	0.115	0.117	0.119	0.121	0.123	0.125	0.127
75	0.113	0.115	0.117	0.119	0.122	0.124	0.126	0.128	0.130
76	0.116	0.118	0.120	0.122	0.124	0.126	0.128	0.130	0.133
77	0.118	0.120	0.122	0.124	0.127	0.129	0.131	0.133	0.136
78	0.120	0.122	0.125	0.127	0.129	0.131	0.134	0.136	0.138
79	0.123	0.125	0.127	0.129	0.132	0.134	0.137	0.139	0.141
80	0.125	0.127	0.130	0.132	0.135	0.137	0.139	0.141	0.144
81	0.128	0.130	0.132	0.134	0.137	0.139	0.142	0.144	0.147
82	0.130	0.132	0.135	0.137	0.140	0.142	0.145	0.147	0.149
83	0.133	0.135	0.138	0.140	0.142	0.145	0.147	0.149	0.152
84	0.135	0.138	0.140	0.142	0.145	0.147	0.150	0.152	0.155
85	0.137	0.139	0.143	0.145	0.148	0.150	0.153	0.155	0.158
86	0.140	0.143	0.145	0.148	0.150	0.153	0.155	0.158	0.161
87	0.142	0.144	0.148	0.150	0.153	0.155	0.158	0.161	0.163
88	0.145	0.147	0.150	0.152	0.155	0.158	0.161	0.163	0.166
89	0.147	0.150	0.153	0.155	0.158	0.161	0.164	0.166	0.169
90	0.150	0.153	0.155	0.157	0.161	0.164	0.166	0.169	0.172
91	0.152	0.155	0.158	0.160	0.163	0.166	0.169	0.172	0.175
92	0.154	0.157	0.160	0.163	0.166	0.169	0.172	0.175	0.177
93	0.157	0.160	0.163	0.166	0.168	0.171	0.174	0.177	0.180
94	0.159	0.162	0.165	0.168	0.171	0.174	0.177	0.180	0.183

TABLE VIII

FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA-LEVEL,
CORRECTION ADDITIVE

Height, in Feet, above Sea.	Temperature of External Air — Degrees Fahrenheit.										
	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
10	0.013	0.012	0.012	0.012	0.012	0.011	0.011	0.011	0.011	0.010	0.010
20	0.025	0.025	0.024	0.023	0.023	0.023	0.022	0.022	0.021	0.021	0.020
30	0.038	0.037	0.036	0.035	0.034	0.034	0.033	0.032	0.032	0.031	0.030
40	0.050	0.049	0.048	0.047	0.046	0.045	0.044	0.043	0.042	0.041	0.040
50	0.063	0.061	0.060	0.059	0.058	0.056	0.055	0.054	0.053	0.052	0.051
60	0.076	0.074	0.072	0.070	0.069	0.068	0.066	0.065	0.063	0.062	0.061
70	0.088	0.086	0.084	0.082	0.081	0.078	0.077	0.076	0.074	0.072	0.071
80	0.101	0.098	0.096	0.094	0.092	0.090	0.088	0.086	0.084	0.082	0.081
90	0.113	0.111	0.108	0.105	0.104	0.101	0.099	0.097	0.095	0.093	0.091
100	0.126	0.123	0.120	0.117	0.115	0.112	0.110	0.108	0.105	0.103	0.101
110	0.139	0.135	0.132	0.129	0.126	0.123	0.121	0.119	0.116	0.113	0.111
120	0.151	0.148	0.144	0.140	0.138	0.134	0.132	0.129	0.126	0.124	0.121
130	0.164	0.160	0.156	0.152	0.149	0.146	0.143	0.140	0.137	0.134	0.131
140	0.176	0.172	0.168	0.164	0.161	0.157	0.154	0.151	0.147	0.144	0.141
150	0.189	0.185	0.180	0.176	0.172	0.168	0.165	0.162	0.158	0.155	0.152
160	0.201	0.197	0.192	0.187	0.183	0.179	0.176	0.172	0.168	0.165	0.162
170	0.214	0.209	0.204	0.199	0.195	0.190	0.187	0.183	0.179	0.175	0.172
180	0.227	0.222	0.216	0.211	0.206	0.202	0.198	0.194	0.189	0.185	0.182
190	0.239	0.234	0.228	0.222	0.218	0.213	0.209	0.204	0.200	0.196	0.192
200	0.252	0.246	0.240	0.234	0.229	0.224	0.220	0.215	0.210	0.206	0.202
210	0.264	0.258	0.252	0.246	0.240	0.235	0.231	0.226	0.221	0.216	0.212
220	0.277	0.270	0.264	0.257	0.252	0.246	0.242	0.236	0.231	0.227	0.222
230	0.289	0.283	0.276	0.269	0.263	0.257	0.253	0.247	0.242	0.237	0.232
240	0.302	0.295	0.288	0.281	0.275	0.269	0.264	0.258	0.252	0.248	0.242
250	0.314	0.307	0.300	0.293	0.286	0.280	0.275	0.269	0.263	0.258	0.253
260	0.327	0.319	0.311	0.304	0.297	0.291	0.285	0.279	0.273	0.268	0.263
270	0.339	0.331	0.323	0.316	0.309	0.302	0.296	0.290	0.284	0.278	0.273
280	0.352	0.344	0.335	0.328	0.320	0.314	0.307	0.301	0.294	0.288	0.283
290	0.364	0.356	0.347	0.339	0.332	0.325	0.318	0.311	0.305	0.299	0.293
300	0.377	0.368	0.359	0.351	0.343	0.336	0.329	0.322	0.315	0.309	0.303
310	0.389	0.380	0.371	0.363	0.354	0.347	0.340	0.333	0.326	0.319	0.313
320	0.402	0.392	0.383	0.374	0.366	0.358	0.351	0.343	0.336	0.329	0.323
330	0.414	0.404	0.395	0.386	0.377	0.369	0.362	0.354	0.347	0.340	0.333
340	0.427	0.416	0.407	0.397	0.389	0.380	0.373	0.365	0.357	0.350	0.343
350	0.439	0.429	0.419	0.409	0.400	0.392	0.384	0.376	0.368	0.360	0.353
360	0.451	0.441	0.430	0.421	0.411	0.403	0.394	0.386	0.378	0.370	0.363
370	0.464	0.453	0.442	0.432	0.423	0.414	0.405	0.397	0.389	0.380	0.373
380	0.476	0.465	0.454	0.444	0.434	0.425	0.416	0.408	0.399	0.391	0.383
390	0.489	0.477	0.466	0.455	0.446	0.436	0.427	0.418	0.410	0.401	0.393

TABLE VIII. — *Continued*

FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA-LEVEL,
CORRECTION ADDITIVE

Height, in Feet, above Sea.	Temperature of External Air — Degrees Fahrenheit.										
	−10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
400	0.501	0.489	0.478	0.467	0.457	0.447	0.438	0.429	0.420	0.411	0.403
410	0.513	0.501	0.490	0.479	0.468	0.458	0.449	0.440	0.430	0.421	0.413
420	0.526	0.513	0.502	0.490	0.480	0.469	0.460	0.450	0.441	0.431	0.423
430	0.538	0.525	0.513	0.502	0.491	0.480	0.470	0.461	0.451	0.442	0.433
440	0.551	0.537	0.525	0.513	0.502	0.491	0.481	0.471	0.462	0.452	0.443
450	0.563	0.550	0.537	0.525	0.513	0.503	0.492	0.482	0.472	0.462	0.453
460	0.575	0.562	0.549	0.537	0.525	0.514	0.503	0.493	0.482	0.472	0.463
470	0.588	0.574	0.561	0.548	0.536	0.525	0.514	0.503	0.493	0.482	0.473
480	0.600	0.586	0.572	0.560	0.547	0.536	0.524	0.514	0.503	0.493	0.483
490	0.613	0.598	0.584	0.571	0.559	0.547	0.535	0.524	0.514	0.503	0.493
500	0.625	0.610	0.596	0.583	0.570	0.558	0.546	0.535	0.524	0.513	0.503
510	0.637	0.622	0.608	0.594	0.581	0.569	0.557	0.545	0.534	0.523	0.513
520	0.650	0.634	0.620	0.606	0.593	0.580	0.568	0.556	0.545	0.533	0.523
530	0.662	0.646	0.631	0.617	0.604	0.591	0.578	0.566	0.555	0.544	0.533
540	0.675	0.658	0.643	0.629	0.615	0.602	0.589	0.577	0.565	0.554	0.543
550	0.687	0.670	0.655	0.640	0.626	0.613	0.600	0.587	0.575	0.564	0.553
560	0.699	0.683	0.667	0.652	0.638	0.624	0.611	0.598	0.586	0.574	0.563
570	0.712	0.695	0.679	0.663	0.649	0.635	0.622	0.608	0.596	0.584	0.573
580	0.724	0.707	0.690	0.675	0.660	0.646	0.632	0.619	0.606	0.595	0.583
590	0.737	0.719	0.702	0.686	0.672	0.657	0.643	0.629	0.617	0.605	0.593
600	0.749	0.731	0.714	0.698	0.683	0.668	0.654	0.640	0.627	0.615	0.603
610	0.761	0.743	0.726	0.709	0.694	0.679	0.665	0.650	0.637	0.625	0.613
620	0.774	0.755	0.738	0.721	0.705	0.690	0.675	0.661	0.648	0.635	0.623
630	0.786	0.767	0.749	0.732	0.717	0.701	0.686	0.671	0.658	0.645	0.633
640	0.798	0.779	0.761	0.744	0.728	0.712	0.697	0.682	0.668	0.655	0.643
650	0.811	0.791	0.773	0.755	0.739	0.723	0.708	0.692	0.679	0.666	0.653
660	0.823	0.803	0.785	0.767	0.750	0.734	0.718	0.703	0.689	0.676	0.662
670	0.835	0.815	0.797	0.778	0.761	0.745	0.729	0.713	0.699	0.686	0.672
680	0.847	0.827	0.808	0.790	0.773	0.756	0.740	0.724	0.709	0.696	0.682
690	0.860	0.839	0.820	0.801	0.784	0.767	0.750	0.734	0.720	0.706	0.692
700	0.872	0.851	0.832	0.813	0.795	0.778	0.761	0.745	0.730	0.716	0.702
710	0.884	0.863	0.844	0.824	0.806	0.789	0.772	0.755	0.740	0.726	0.712
720	0.896	0.875	0.855	0.836	0.817	0.800	0.782	0.766	0.751	0.736	0.722
730	0.909	0.887	0.867	0.847	0.829	0.811	0.793	0.776	0.761	0.746	0.732
740	0.921	0.899	0.879	0.859	0.840	0.822	0.804	0.787	0.771	0.756	0.742
750	0.933	0.911	0.891	0.870	0.851	0.833	0.815	0.797	0.782	0.767	0.752
760	0.945	0.922	0.902	0.881	0.862	0.843	0.825	0.808	0.792	0.777	0.761
770	0.957	0.934	0.914	0.893	0.873	0.854	0.836	0.818	0.802	0.787	0.771
780	0.970	0.946	0.926	0.904	0.885	0.865	0.847	0.829	0.812	0.797	0.781
790	0.982	0.958	0.937	0.916	0.896	0.876	0.857	0.839	0.823	0.807	0.791

TABLE VIII.—Continued

FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA-LEVEL,
CORRECTION ADDITIVE

Height, in Feet, above Sea.	Temperature of External Air—Degrees Fahrenheit.										
	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
800	0.994	0.970	0.949	0.927	0.907	0.887	0.868	0.850	0.833	0.817	0.801
810	1.006	0.982	0.961	0.938	0.918	0.898	0.878	0.860	0.843	0.827	0.811
820	1.018	0.994	0.972	0.950	0.929	0.909	0.889	0.871	0.854	0.837	0.821
830	1.031	1.006	0.984	0.961	0.940	0.920	0.900	0.881	0.864	0.847	0.831
840	1.043	1.018	0.995	0.973	0.951	0.931	0.911	0.892	0.874	0.857	0.841
850	1.055	1.030	1.007	0.984	0.962	0.942	0.922	0.902	0.885	0.867	0.851
860	1.067	1.041	1.019	0.995	0.974	0.952	0.932	0.913	0.895	0.877	0.860
870	1.079	1.053	1.030	1.007	0.985	0.963	0.943	0.923	0.905	0.887	0.870
880	1.092	1.065	1.042	1.018	0.996	0.974	0.954	0.934	0.915	0.897	0.880
890	1.104	1.077	1.053	1.030	1.007	0.985	0.964	0.944	0.926	0.907	0.890
900	1.116	1.089	1.065	1.041	1.018	0.996	0.975	0.955	0.936	0.917	0.900
910	1.128	1.101	1.077	1.052	1.029	1.007	0.986	0.965	0.946	0.927	0.910
920	1.140	1.113	1.088	1.064	1.040	1.018	0.996	0.976	0.956	0.937	0.920
930	1.152	1.125	1.100	1.075	1.051	1.029	1.007	0.986	0.967	0.947	0.929
940	1.164	1.137	1.111	1.086	1.062	1.040	1.017	0.997	0.977	0.957	0.939
950	1.177	1.149	1.123	1.098	1.074	1.051	1.028	1.007	0.987	0.967	0.949
960	1.189	1.160	1.135	1.109	1.085	1.061	1.039	1.017	0.997	0.977	0.959
970	1.201	1.172	1.146	1.121	1.096	1.072	1.049	1.028	1.007	0.987	0.969
980	1.213	1.184	1.158	1.130	1.107	1.083	1.060	1.038	1.018	0.997	0.978
990	1.225	1.196	1.169	1.143	1.118	1.094	1.070	1.049	1.028	1.007	0.988
1000	1.237	1.208	1.181	1.154	1.129	1.105	1.081	1.059	1.038	1.017	0.998
1010	1.249	1.220	1.192	1.165	1.140	1.116	1.092	1.069	1.048	1.027	1.008
1020	1.261	1.232	1.204	1.177	1.151	1.127	1.102	1.080	1.058	1.037	1.018
1030	1.273	1.243	1.215	1.188	1.162	1.137	1.113	1.090	1.069	1.047	1.027
1040	1.285	1.255	1.227	1.199	1.173	1.148	1.123	1.101	1.079	1.057	1.037
1050	1.298	1.267	1.238	1.211	1.184	1.159	1.134	1.111	1.089	1.067	1.047
1060	1.310	1.279	1.250	1.222	1.195	1.170	1.145	1.121	1.099	1.077	1.057
1070	1.322	1.291	1.261	1.233	1.206	1.181	1.155	1.132	1.109	1.087	1.067
1080	1.334	1.302	1.273	1.244	1.217	1.191	1.166	1.142	1.120	1.097	1.076
1090	1.346	1.314	1.284	1.256	1.228	1.202	1.176	1.153	1.130	1.107	1.086
1100	1.358	1.326	1.296	1.267	1.239	1.213	1.187	1.163	1.140	1.117	1.096
1110	1.370	1.338	1.307	1.278	1.250	1.224	1.198	1.173	1.150	1.127	1.106
1120	1.382	1.350	1.319	1.289	1.261	1.235	1.208	1.184	1.160	1.137	1.115
1130	1.394	1.361	1.330	1.301	1.272	1.245	1.219	1.194	1.170	1.147	1.125
1140	1.406	1.373	1.342	1.312	1.283	1.256	1.229	1.204	1.180	1.157	1.135
1150	1.418	1.385	1.353	1.323	1.294	1.267	1.240	1.215	1.191	1.167	1.145
1160	1.430	1.397	1.365	1.334	1.305	1.278	1.251	1.225	1.201	1.177	1.154
1170	1.442	1.409	1.376	1.345	1.315	1.289	1.261	1.235	1.211	1.187	1.164
1180	1.454	1.420	1.388	1.357	1.327	1.299	1.272	1.245	1.221	1.197	1.174
1190	1.466	1.432	1.399	1.368	1.338	1.310	1.282	1.256	1.231	1.207	1.183

TABLE VIII.—*Continued*

FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA-LEVEL,
CORRECTION ADDITIVE

Height, in Feet, above Sea.	Temperature of External Air—Degrees Fahrenheit.										
	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
1200	1.478	1.444	1.411	1.379	1.349	1.321	1.293	1.266	1.241	1.217	1.193
1210	1.490	1.456	1.422	1.390	1.360	1.332	1.303	1.276	1.251	1.227	1.203
1220	1.502	1.467	1.434	1.401	1.371	1.342	1.314	1.288	1.261	1.237	1.212
1230	1.514	1.479	1.445	1.413	1.382	1.353	1.324	1.297	1.271	1.247	1.222
1240	1.526	1.491	1.457	1.424	1.393	1.364	1.335	1.307	1.281	1.257	1.232
1250	1.538	1.502	1.468	1.435	1.401	1.374	1.345	1.317	1.291	1.266	1.242
1260	1.550	1.514	1.479	1.446	1.415	1.385	1.356	1.328	1.302	1.276	1.251
1270	1.562	1.526	1.491	1.457	1.426	1.396	1.366	1.338	1.312	1.286	1.261
1280	1.574	1.538	1.502	1.469	1.437	1.407	1.377	1.348	1.322	1.296	1.271
1290	1.586	1.549	1.514	1.480	1.448	1.417	1.387	1.359	1.332	1.306	1.280
1300	1.598	1.561	1.525	1.491	1.459	1.428	1.398	1.369	1.342	1.316	1.290
1310	1.610	1.573	1.536	1.502	1.470	1.439	1.408	1.379	1.352	1.326	1.300
1320	1.622	1.584	1.548	1.513	1.481	1.449	1.419	1.390	1.362	1.336	1.309
1330	1.634	1.596	1.559	1.525	1.492	1.460	1.429	1.400	1.372	1.346	1.319
1340	1.646	1.608	1.571	1.536	1.503	1.471	1.440	1.410	1.382	1.356	1.329
1350	1.658	1.620	1.582	1.547	1.514	1.482	1.450	1.420	1.393	1.366	1.339
1360	1.669	1.631	1.593	1.558	1.524	1.492	1.461	1.431	1.403	1.375	1.348
1370	1.681	1.643	1.605	1.569	1.535	1.503	1.471	1.441	1.413	1.385	1.358
1380	1.693	1.655	1.616	1.581	1.546	1.514	1.482	1.451	1.423	1.395	1.368
1390	1.705	1.666	1.628	1.592	1.557	1.524	1.492	1.462	1.433	1.405	1.377
1400	1.717	1.678	1.639	1.603	1.568	1.535	1.503	1.472	1.443	1.415	1.387
1410	1.729	1.690	1.650	1.614	1.579	1.546	1.513	1.482	1.453	1.425	1.397
1420	1.741	1.701	1.662	1.625	1.590	1.556	1.524	1.492	1.463	1.435	1.406
1430	1.753	1.713	1.673	1.636	1.601	1.567	1.534	1.503	1.473	1.444	1.416
1440	1.765	1.724	1.685	1.647	1.612	1.577	1.545	1.513	1.483	1.454	1.426
1450	1.777	1.736	1.696	1.658	1.623	1.588	1.555	1.523	1.493	1.464	1.436
1460	1.788	1.748	1.707	1.670	1.633	1.599	1.565	1.533	1.503	1.474	1.445
1470	1.800	1.759	1.719	1.681	1.644	1.609	1.576	1.543	1.513	1.484	1.455
1480	1.812	1.771	1.730	1.692	1.655	1.620	1.586	1.554	1.523	1.493	1.465
1490	1.824	1.782	1.742	1.703	1.666	1.630	1.597	1.564	1.533	1.503	1.474
1500	1.836	1.794	1.753	1.714	1.677	1.641	1.607	1.574	1.543	1.513	1.484

ELEVATION ABOVE SEA-LEVEL OF THE GREAT LAKES

Lake Superior, 602 ft. Lake Huron, 581 ft.

Lake Michigan, 581 ft. Lake Erie, 573 ft.

Lake Ontario, 247 ft.

TABLE IX

BOILING TEMPERATURE t OF WATER FOR DIFFERENT BAROMETRIC PRESSURES b (From Regnault's observations)

b mm.	t°	b mm.	t°	b mm.	t°
680	96.92	720	98.50	760	100.00
81	96.96	21	.54	61	.04
82	97.00	22	.57	62	.07
83	.05	23	.61	63	.11
84	.09	24	.65	64	.15
85	.13	25	.69	65	.18
86	.17	26	.73	66	.22
87	.21	27	.77	67	.26
88	.25	28	.80	68	.29
689	97.29	29	.84	69	.33
		730	98.88	770	100.36
690	97.32				
91	.36	731	98.92	771	100.40
92	.40	32	.96	72	.44
93	.44	33	98.99	73	.47
94	.48	34	99.03	74	.51
95	.52	35	.07	75	.55
96	.56	36	.11	76	.58
97	.60	37	.14	77	.62
98	.64	38	.18	78	.65
699	.68	39	.22	79	.69
700	97.72	740	99.26	780	100.73
701	97.76	741	99.30		
02	.80	42	.33		
03	.84	43	.37		
04	.88	44	.41		
05	.92	45	.44		
06	.96	46	.48		
07	97.99	47	.52		
08	98.03	48	.56		
09	.07	49	.59		
710	98.11	750	99.63		
711	98.15	751	99.67		
12	.19	52	.71		
13	.23	53	.74		
14	.27	54	.78		
15	.31	55	.82		
16	.34	56	.85		
17	.38	57	.89		
18	.42	58	.93		
19	.46	59	.96		
720	98.50	760	100.00		

TABLE X

COEFFICIENTS OF LINEAR EXPANSION

Aluminum	0.00002221	Lead	0.00002798
Brass	0.00001875	Silver	0.00001943
Copper	0.000017	Steel, tempered . .	0.00001322
Iron, cast	0.00001125	Steel, untempered .	0.00001095
Iron, wrought	0.00001220	Zinc	0.00002978

TABLE XI

SPECIFIC HEATS

Aluminum	0.2122	Lead	0.0315
Brass	0.086	Mercury	0.0335
Copper	0.0933	Nickel	0.1092
Ice	0.504	Silver	0.0559
Iron	0.1124	Zinc	0.0935
Glass	0.1770		

TABLE XII

SIZE OF WIRE, ETC. AMERICAN GAUGE (B. & S.)

Gauge No.	Size.				Pure Copper Wire.			
	Diameter in		Square of Diameter in Mils.	Area in Sq. In.	Weight.		Resistance at 24° C. or 76° F.	
					Lbs. per 1000 Ft.	Ft. per Lb.	Ohms per 1000 Ft.	Ohms per Lb.
	Mils.	Millim.						
0000	460.00	11.684	211600.0	.166191	639.33	1.56	.051	.0000798
000	409.64	10.405	167805.0	.131790	507.01	1.97	.064	.000127
00	364.80	9.266	133079.4	.104590	402.09	2.49	.081	.000202
0	324.95	8.254	105592.5	.082932	319.04	3.13	.102	.000320
1	289.80	7.348	83694.2	.065737	252.88	3.95	.129	.00051
2	257.63	6.544	66378.0	.052130	200.54	4.99	.163	.000811
3	229.42	5.827	52634.0	.041339	159.03	6.29	.205	.001288
4	204.31	5.189	41742.0	.032734	126.12	7.93	.259	.00205
5	181.94	4.621	33102.0	.025998	100.01	10.00	.326	.00326
6	162.02	4.115	26250.5	.020617	79.32	12.61	.411	.00518
7	144.28	3.665	20516.0	.016349	62.90	15.90	.519	.00824
8	128.49	3.264	16509.0	.012766	49.88	20.05	.654	.01311
9	114.43	2.907	13094.0	.010234	39.56	25.28	.824	.02038
10	101.89	2.588	10381.0	.008153	31.37	31.88	1.040	.03314
11	90.74	2.305	8234.0	.006467	24.38	40.20	1.311	.05269
12	80.81	2.058	6529.9	.005129	19.73	50.69	1.638	.08377
13	71.96	1.823	5173.4	.004067	15.65	63.91	2.084	.13321
14	64.01	1.623	4106.8	.003147	12.41	80.59	2.628	.2118
15	57.07	1.450	3256.7	.002535	9.84	101.63	3.314	.3368
16	50.82	1.291	2582.9	.002029	7.81	128.14	4.179	.5355
17	45.26	1.150	2048.2	.001609	6.19	161.59	5.269	.8515
18	40.30	1.024	1624.3	.001276	4.91	203.76	6.645	1.3536
19	35.39	.899	1252.4	.000934	3.78	264.26	8.617	2.2772
20	31.96	.812	1021.5	.000802	3.09	324.00	10.566	3.423
21	28.462	.728	810.1	.000636	2.45	408.56	13.323	5.443
22	25.85	.644	642.7	.000505	1.94	515.15	16.799	8.654
23	22.57	.573	509.5	.000400	1.54	649.66	21.185	13.763
24	20.10	.511	404.0	.000317	1.22	819.21	26.718	21.835
25	17.90	.455	320.4	.000252	.97	1032.96	33.684	34.795
26	15.94	.405	254.0	.000199	.77	1302.61	42.477	55.331
27	14.19	.361	201.5	.000158	.61	1642.55	53.568	87.979
28	12.64	.321	159.8	.000125	.48	2071.22	67.542	139.893
29	11.26	.286	126.7	.000100	.38	2611.82	85.170	222.449
30	10.08	.255	100.5	.000079	.30	3298.97	107.391	353.742
31	8.98	.227	79.7	.000063	.24	4152.22	135.402	562.221
32	7.95	.202	63.2	.000050	.19	5236.66	170.765	894.242
33	7.08	.180	50.1	.000039	.15	6602.71	215.312	1421.646
34	6.30	.160	39.7	.000031	.12	8328.30	271.588	2261.82
35	5.61	.143	31.5	.000025	.10	10501.35	342.443	3596.104
36	5.00	.127	25.0	.000020	.08	13238.33	431.712	6715.36
37	4.45	.113	19.8	.000016	.06	16691.06	544.287	9084.71
38	3.96	.101	15.7	.000012	.05	20354.65	686.511	14320.26
39	3.53	.090	12.5	.000010	.04	26302.23	865.046	22752.6
40	3.14	.080	9.9	.000008	.03	33175.94	1091.865	36223.59

TABLE XIII

SIZES AND NUMBERS OF STEEL MUSIC OR PIANO WIRE (ENGLISH)

No. of Gauge.	Diameter in Inches.	No. of Gauge.	Diameter in Inches.	No. of Gauge.	Diameter in Inches.
2	0.0105	11	0.0270	21	0.0445
3	0.0115	12	0.3285	22	0.0470
4	0.0125	13	0.0305	23	0.0490
5	0.0145	14	0.0320	24	0.0530
6	0.0150	15	0.0350	25	0.0560
7	0.0175	16	0.0360	26	0.0605
8	0.0190	17	0.0380	27	0.0640
9	0.0220	18	0.0400	28	0.0685
10	0.0245	19	0.0420	29	0.0715
		20	0.0430	30	0.0750

TABLE XIV

APPROXIMATE ELECTROMOTIVE FORCE OF PRIMARY BATTERIES

Daniell's, amalgamated zinc, $\text{H}_2\text{SO}_4 + 4 \text{ Aq.}$, CuSO_4 , con. sol.	1.079 volts.
" " " " + 12 " " "	0.978 "
" " " " + 12 Aq., CuNO_3 , " "	1.000 "
" equi-dense solutions of ZnSO_4 , and CuSO_4 plates of pure Zn and Cu	1.104 "
Bunsen, amalgamated zinc, $\text{H}_2\text{SO}_4 + 12 \text{ Aq.}$, and HNO_3 , carbon	1.964 "
Grove, amalgamated zinc, $\text{H}_2\text{SO}_4 + 12 \text{ Aq.} + 4 \text{ Aq.}$, HNO_3 , platinum	1.956 "
Leclanché, zinc in saturated solution of NH_4Cl	1.32 "
Potassium bichromate	2.00 "
Carhart Clark standard cell	1.44 "

TABLE XV

VELOCITY OF SOUND AT 0° C.

	Meters		Meters
Air per sec.	332	Maple per sec.	4106
Ash "	4668	Oak "	3847
Brass "	3318	Oxygen "	317
Carbon dioxide "	261	Pine "	3322
Copper "	3556	Steel "	5237
Glass "	4526	Water at 8°.1 "	1435
Iron "	5127		

TABLE XVI

INDICES OF REFRACTION (FOR THE D LINE)

Air	1.000294	Diamond	2.47 to 2.75
Alcohol, ethyl	1.361	Flint glass	1.57 to 1.71
Benzine	1.49	Glycerine	1.47
Canada balsam	1.54	Ice	1.310
Carbon disulphide	1.626	Water	1.332
Crown glass	1.5150		

TABLE XVII

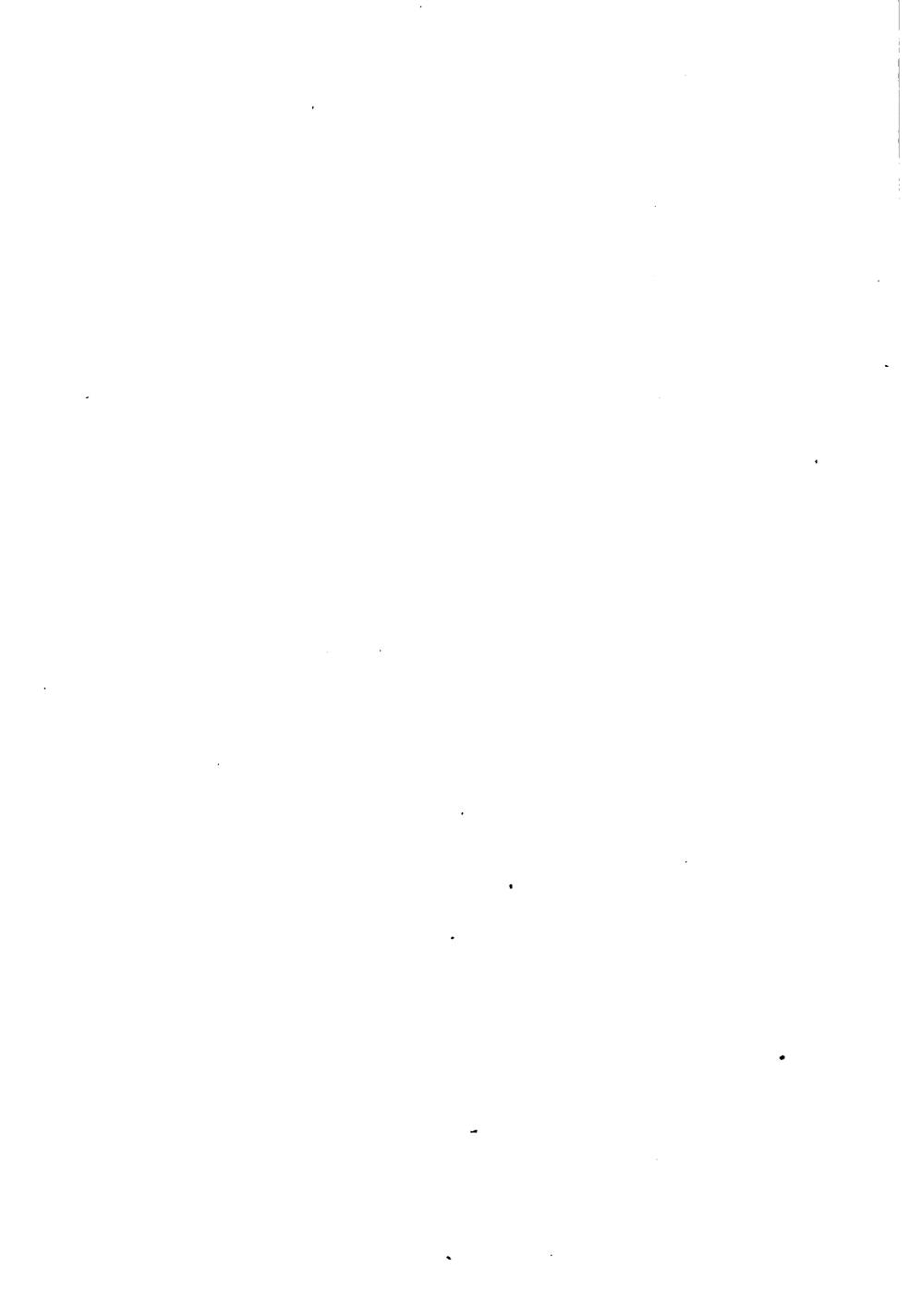
TRIGONOMETRICAL FUNCTIONS

For angles greater than 45° , find the degrees in the last right-hand column, reading from the bottom up, and using the names at the bottom of the columns. When the function for a fraction of a degree is required, find the function for the whole number of degrees, and add to it the product obtained by multiplying the difference between that number and that for the next degree by the decimal parts of the degree. D. = differences.

Angle.	Sine.	D.	Tangent.	D.	Cotangent.	D.	Cosine.	D.	Angle.
0	0.000		0.000				1.000		90
1	0.017	17	0.017	17	57.29		1.000	0	89
2	0.035	18	0.035	18	28.64		0.999	1	88
3	0.052	17	0.052	17	19.08		0.999	0	87
4	0.070	18	0.070	18	14.30		0.998	2	86
5	0.087	17	0.087	17	11.43		0.996	1	85
6	0.105	18	0.105	18	9.514		0.995	2	84
7	0.122	17	0.123	18	8.144		0.993	3	83
8	0.139	17	0.141	17	7.115	841	0.990	2	82
9	0.156	18	0.158	18	6.314	643	0.988	3	81
10	0.174	17	0.176	18	5.671	526	0.985	3	80
11	0.191	17	0.194	18	5.145	440	0.982	4	79
12	0.208	17	0.213	19	4.705	374	0.978	4	78
13	0.225	17	0.231	18	4.331	320	0.974	4	77
14	0.242	17	0.249	19	4.011	279	0.970	4	76
15	0.259	17	0.268	19	3.732	245	0.966	5	75
16	0.276	17	0.287	19	3.487	216	0.961	5	74
17	0.292	16	0.306	19	3.271	193	0.956	5	73
18	0.309	17	0.325	19	3.078	174	0.951	5	72
19	0.326	16	0.344	20	2.904	157	0.946	6	71
Angle.	Cosine.	D.	Cotangent.	D.	Tangent.	D.	Sine.	D.	Angle.

TABLE XVII.—*Continued*
TRIGONOMETRICAL FUNCTIONS

Angle.	Sine.	D.	Tangent.	D.	Cotangent.	D.	Cosine.	D.	Angle.
20	0.342	16	0.364	20	2.747	142	0.940	6	70
21	0.358	17	0.384	20	2.605	130	0.934	7	69
22	0.375	16	0.404	20	2.475	119	0.927	6	68
23	0.391	16	0.424	21	2.356	110	0.921	7	67
24	0.407	16	0.445	21	2.246	101	0.914	8	66
25	0.423	15	0.466	22	2.145	95	0.906	7	65
26	0.438	15	0.488	22	2.050	87	0.899	8	64
27	0.454	15	0.510	22	1.963	82	0.891	8	63
28	0.469	16	0.532	22	1.881	77	0.883	8	62
29	0.485	15	0.554	23	1.804	72	0.875	9	61
30	0.500	15	0.577	24	1.732	68	0.866	9	60
31	0.515	15	0.601	24	1.664	64	0.857	9	59
32	0.530	15	0.625	24	1.600	60	0.848	9	58
33	0.545	14	0.649	26	1.540	57	0.839	10	57
34	0.559	15	0.675	25	1.483	55	0.829	10	56
35	0.574	14	0.700	27	1.428	52	0.819	10	55
36	0.588	14	0.727	27	1.376	49	0.809	10	54
37	0.602	14	0.754	27	1.327	47	0.799	11	53
38	0.616	13	0.781	29	1.280	45	0.788	11	52
39	0.629	14	0.810	29	1.235	43	0.777	11	51
40	0.643	13	0.839	30	1.192	42	0.766	11	50
41	0.656	13	0.869	31	1.150	39	0.755	12	49
42	0.669	13	0.900	33	1.111	39	0.743	12	48
43	0.682	13	0.933	33	1.072	36	0.731	12	47
44	0.695	12	0.966	34	1.036	36	0.719	12	46
45	0.707		1.000		1.000		0.707		45
Angle.	Cosine.	D.	Cotangent.	D.	Tangent.	D.	Sine.	D.	Angle.



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